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Pecan Industry: Current Situation and Future Challenges, Third National Pecan Workshop Proceedings

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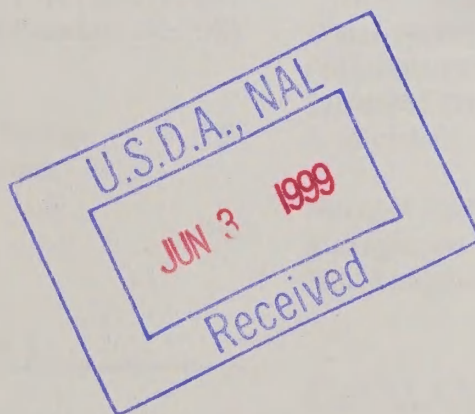
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Preface

This, the third National Pecan Scientists Workshop, succeeds the first held in June, 1990 at Unicor State Park, Georgia and the second held in July, 1994 at Fountainhead State Park, Wagoner, OK. The program listed the focal point of this workshop as "The Pecan Industry: Current Situation and Future Challenges."

Since the last workshop, the pecan industry has been subjected to the usual onslaught of natural occurrences including early and late freezes, hurricanes, tornadoes, ice storms, droughts and floods among others. Since the last workshop the, US Crop Reporting Board has reported the price for native pecans ranging from $0.52 to $0.78 and cultivars from $0.99 to $1.51 per pound. According to US Crop Reporting Board Statistics the US crop ranged from 199 million pounds to 338 million pounds during the same time.

Pecan growers like most other American farmers are fiercely protective of their individuality and generally oppose governmental intervention into their business. At the same time growers are becoming more aware that public funding for research and extension support for their industry is becoming more scarce each year. Competition for market share has become more intense from other commodities as well as production from other countries. Consumers are also more conscious of health attributes of foods as well as cost. As a result, marketing and promotion programs have taken on even more significance in protecting as well as expanding market share. In light of reduced public funding grower organizations have taken a new look at initiatives to procure industry funds to supplement public resources. As a result, two states, Georgia and Texas have passed grower initiatives to raise funds to support research, education and product promotion.

Governmental emphasis on pesticide use reduction and measures aimed at environmental protection continue at the same or accelerated pace. Legislative initiatives originating at the United States Environmental Protection Agency continue to challenge availability of pesticides, e.g. organophosphates, for use in management programs. This has caused continued or increased emphasis on pest management programs, sustainable management initiatives and alternative management strategies such as predictive modeling and environmentally sensitive pesticides.

Relatively new initiatives that have received attention in the last 4 years include pecan oil extraction, medicinal uses of pecans and rootstocks particularly for northern production areas.

These proceedings include papers contributed by each author that address all these issues and more. They are arranged by section as listed in the program. When available, recorder's discussion notes are included at the end of each session.

The following persons participated in planning and implementation of this workshop:

Coordinator	Esteban Herrera
Entomology	Marvin Harris and John McVay
Plant Pathology	Charles Reilley & Paul Bertrand
Agric. Economics	Wojciech Florkowski and Jose Pena
Horticulture	Bruce Wood and Mike Kilby
Poster sessions	Steve Sibbett
Proceedings	Dean McCraw

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FUNGICIDE RESISTANCE MANAGEMENT IN PECANS

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Additional index words. Pecan scab, disease control, fungicide sensitivity

Introduction

Production of high quality pecans, particularly in the southeastern U.S., is dependent on availability of effective fungicides for disease control. A potential threat to the effectiveness of fungicides is the development of resistance to these compounds in pathogen populations. Fungicide resistance builds up in a pathogen population through the process of selection during repeated exposure to fungicide treatment, leading to the survival and spread of initially rare mutants (Brent 1995). Field resistance occurs when the frequency of resistant individuals in the pathogen population reaches a high level, resulting in substantially reduced efficacy or complete failure of the fungicide. The development of resistance may arise rapidly through qualitative population change (due to mutations in a single gene), or more gradually through a quantitative population change (controlled by multiple genes) (Köller 1991). The speed at which resistance develops is also influenced by epidemiology of the disease, susceptibility of the host, characteristics of the fungicide and the mode of application.

As a direct result of hard lessons learned from benomyl and other early systemic fungicides during the 1960's and 1970's, there is a heightened awareness in the agricultural community of the potential for resistance and the economic consequence of its occurrence (Russell 1995). The data collected over the past twenty five years have provided convincing evidence in support of the need for development and application of appropriate resistance management programs to prolong the effective life of new and existing agricultural fungicides.

Assessing the Risk of Fungicide Resistance

Most manufacturers of agricultural fungicides now include assessment of resistance risk and resistance management as a routine part of the development, labeling and marketing of new fungicides, well before the product is available on the market. Although it is difficult to predict reliably, the relative risk of resistance to new fungicides can be assessed based on characteristics of the target fungal pathogen, properties of the fungicide, and other factors associated with fungicide application (Brent 1995).

Pathogen and disease-related factors. The most important characteristics of the pathogen and disease that influence the likelihood of resistance are the number of reproductive cycles completed by the pathogen during a season and the potential for genetic variation in the pathogen population. High reproductive capacity leads to rapid population growth and provides increased opportunity for exposure of large populations to the selective pressure of fungicide exposure and rapid multiplication of resistant mutants. Populations of fungi that reproduce sexually are likely to be more genetically variable than those that reproduce only asexually. Greater genetic variation within a pathogen population provides greater opportunity for emergence of resistant mutants.

Fungicide and applications-related factors. The fungicide-related factors that are most closely associated with the risk of fungicide resistance development are the chemical class and mode of action of the compound and the frequency of application. A greater risk of resistance is associated with fungicides that have a very specific biochemical target site of action compared to those that have a non-specific mode of action. In general, resistance will develop much faster in pathogen populations that are exposed to more frequent applications of fungicide than in those that are exposed infrequently.

General Strategies for Resistance Management

Fungicide resistance management strategies are aimed at delaying, not preventing, the development of resistance. The only way to prevent the occurrence of fungicide resistance is to not use the fungicide. However, the careful use of at-risk fungicides can reduce the risk of resistance and delay the occurrence of resistance problems in the field. Resistance management strategies are most effective when applied prior to any detection of resistance. Once resistance has developed in a pathogen population, it is extremely difficult or impossible to eliminate it. Therefore, it is very important that resistance management strategies be implemented prior to detection of resistance (Bertrand and Padgett 1997).

General guidelines for fungicide resistance management can be summarized as follows (Brent

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1995):

1. *Do not use an at-risk fungicide in isolation.*
Exclusive use of an at-risk compound places great selection pressure on the pathogen population and should be avoided. At-risk compounds should always be applied in combination with an appropriate fungicide partner. An appropriate partner is one that is chemically unrelated to the at-risk fungicide (i.e., a different mode of action), is not cross-resistant with the at-risk fungicide, and preferably has a non-specific mode of action with a relatively low risk of resistance. The choice of a appropriate partner with systemic, curative or protectant activity will also depend on the use situation (Urech 1988). Fungicide partners can be applied either as a tank mix (usually at reduced rates of both compounds) or applied in alternation, either as single applications, or in blocks of two or more applications of each fungicide.

2. *Restrict the number of applications per season.*
Reducing the number of applications of an at-risk fungicide will help to reduce exposure of the pathogen population to selection pressure imposed by the fungicide.

3. *Maintain recommended dose.*
Use of less than effective doses will lead to larger pathogen populations and increase exposure to the fungicide. In addition, use of less than effective doses may encourage the development of resistance through quantitative population changes. On the other hand, very high doses place excessive selection pressure on the pathogen population and encourage rapid selection of very resistant individuals. Resistance that develops through qualitative population changes is especially favored by use of very high doses.

4. *Avoid eradicant use.*
Application of fungicides with eradicant or curative activity made after infection has occurred and disease symptoms are visible result in exposure of larger pathogen populations to the selective pressure of the fungicide than when fungicide is applied as a protectant before infection occurs. Post-infection application should also be avoided when using reduced rate mixtures that include a partner that has no significant eradicant activity.

5. *Maintain chemical diversity.*
Incorporation of several fungicides with different modes of action into a disease management program will help to delay development of resistance.

6. *Practice integrated disease management.*

To prolong the useful life of any fungicide, it should only be applied when necessary, and always in combination with cultural practices, use of resistant cultivars, and other non-chemical means of disease control (De Waard et al. 1993). The development of successful disease forecasting systems may also help to optimize the use of fungicides.

Fungal Diseases of Pecan and Relative Risk of Resistance

The pecan is susceptible to attack by variety of different fungi. However, by far, the major target of fungicide use on pecan is the fungus *Cladosporium caryigenum*, the fungus responsible for pecan scab. Based on a survey of pecan growers in Georgia (Bertrand and Hadden 1992), seven fungicide applications are made, on average, to control scab during a single growing season, but as many as eleven applications may be made during an unusually wet season or on a highly susceptible cultivar. Multiple applications of fungicide are necessary because the fungus can complete many reproductive cycles during the course of a growing season (polycyclic) and young, susceptible pecan tissue (leaves or fruit) is produced throughout the season. Pathogen development and infection are favored by warm wet weather, and under optimal conditions the fungus can complete a reproductive cycle in as little as 7-10 days. Although sexual reproduction is not known to occur in this fungus, the capacity for asexual reproduction during a given growing season is quite high. This is especially true during wet years or on highly susceptible cultivars.

Pecan Fungicides and Relative Risk of Resistance

Fungicides labeled for use on pecan fall into several different general chemical classes with different modes of action and associated risks of resistance (Table 1).

Benzimidazoles. Benomyl (Benlate) and thiophanate methyl (Topsin-M) are members of the benzimidazole class of fungicides. These systemic compounds interfere with cell division in the fungus by site-specific inhibition of tubulin biosynthesis (Davidse 1973). A high degree of risk of resistance is associated with the benzimidazoles, due to the very site-specific mode of action of these fungicides and the single-gene control of resistance. Indeed, widespread use during the late 1960's and early 1970's lead to a very rapid development of resistance in a wide variety of fungal pathogens. Benomyl resistance in the pecan scab fungus was first detected in 1975 after only three years of effective control (Littrell 1976).

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Table 1. Major fungicides labeled for use on pecan.

Fungicide Class	Compound	Relative Risk of Resistance
benzimidazoles	benomyl (Benlate)	high
	thiophanate methyl (Topsin-M)	high
DMIs	propiconazole (Orbit)	moderate
	fenbuconazole (Enable)	moderate
strobilurins	azoxystrobin (Abound)	moderate
other	fentin hydroxide (Super Tin)	low
	ziram (Ziram)	low
	dodine (Syllit)	moderate

Demethylation inhibitors (DMIs). Propiconazole (Orbit) and fenbuconazole (Enable) are members of the triazoles, the largest of three groups of fungicidal compounds that comprise the C-14 demethylation inhibitors (DMIs), which together with the morpholines, are referred to as sterol biosynthesis inhibitors (SBIs)(Köller 1992). These systemic compounds prevent fungal growth by site-specific inhibition of ergosterol biosynthesis. The DMIs are very effective for control of diseases on a wide variety of crops, including pecan scab. Propiconazole and fenbuconazole are particularly effective during the early part of the season (prepollination). They also provide an additional benefit of providing some eradicant activity by halting development of the fungus when applied within a limited time after infection has occurred (Reilly and Wood 1997). However, because of the site-specific mode of action of the DMIs, a moderate risk of resistance is associated with these highly effective compounds. Although resistance to DMIs has not been reported in the pecan scab fungus, resistance has been documented in many important fungal plant pathogens (Russell 1995). Unlike resistance to benzimidazoles, resistance to DMIs appears to come about gradually, by means of directional selection.

Strobilurins. Azoxystrobin (Abound), the newest fungicide labeled for scab control on pecan, is a member of the strobilurin fungicides. This group of fungicides is comprised of synthetic derivatives of strobilurin A, a naturally fungicidal compound produced by the basidiomycete fungus *Strobilurus tenacellus* (Godwin et al. 1992). The strobilurins have an unusually broad spectrum of activity and prevent fungal growth through inhibition of cellular respiration by blocking electron transport in mitochondria. Like most of the modern synthetic fungicides, the mode of action of the strobilurins is very site-specific and is associated with a moderate risk of resistance, similar to that of the DMIs. Although it has been shown to be highly efficacious against the pecan scab fungus, azoxystrobin has only recently become available and has not yet been very widely used on pecans. Resistant strains of fungal pathogens have been artificially induced in the laboratory (Ziogas et al. 1997), but no field resistance to the strobilurins has been reported.

Others. Fentin hydroxide (Super Tin), ziram (Ziram), and dodine (Syllit) are among the oldest of the fungicides currently available for scab control. These compounds are non-systemic in nature and most effective when applied as protectants. These compounds all have a non-specific, multi-site mode of action. With the exception of dodine, these fungicides are considered to be associated with a relatively low risk of resistance. Despite its non-specific mode of action, a relatively moderate risk of resistance may be associated with dodine. Field resistance to dodine has been reported in a number of pathogens, including the apple scab fungus, *Venturia inaequalis*, a close relative of *C. caryigenum* (Szkolnik and Gilpatrick 1969, Jones and Walker 1976).

Implementation of Resistance Management in Pecan Disease Control Programs

The current recommendations for resistance management in pecan disease control programs are aimed primarily at reducing the risk of development of resistance to the DMIs. However, with the recent addition of azoxystrobin and the likelihood of registration of other strobilurins on pecans in the near future, consideration must be given to management of resistance to strobilurins as well as DMIs. Unlike the DMIs, which are used extensively for pecan disease control, benomyl, thiophanate methyl, and dodine make up a relatively small proportion of the fungicides that are used on pecans. However, because these fungicides are also considered at-risk, they should always be applied in accordance with resistance management guidelines.

DMIs. Management of DMI resistance in pecans is currently based on three approaches: reducing the number of applications per season (or total amount of material), applying as a reduced rate tank-mix

combination with fentin hydroxide, or alternation with fentin hydroxide or other chemically unrelated fungicides. Propiconazole is currently available for use on pecan only in a pre-packaged combination with fentin hydroxide, and must be applied as a tank-mix with a limit of eight applications per season. The DMI fenbuconazole (Enable) is still available as a stand-alone compound for pecan disease control and the total amount of material applied per season is limited to 48 oz. per acre. To delay development of DMI resistance, fenbuconazole can be applied either in alternating single or block sprays or full season as a reduced-rate tank-mix with fentin hydroxide. Sensitivities of isolates of *C. caryigenum* to propiconazole and fenbuconazole have been found to be highly correlated (Reynolds et al. 1997). Therefore, these two fungicides should never be alternated or tank-mixed. If fenbuconazole is used alone during the early part of the season, tank mixes of fenbuconazole or propiconazole later in the season should be avoided in order to minimize selection pressure on the pathogen population. Post-infection application of reduced-rate mixtures of DMIs and fentin hydroxide should be avoided due to insufficient post-infection activity of fentin hydroxide (Reilly and Wood 1997).

Strobilurins. Because of its single-site mode of action and moderate resistance risk, azoxystrobin should be applied in accordance with general resistance management principles. Current label restrictions limit the total amount of fungicide to 1.2 lb a.i. per acre per season in order to reduce exposure to the fungicide and selection pressure on the pathogen population. And as with other at-risk compounds, exclusive use of the strobilurins full season should be avoided. Applications of azoxystrobin should be alternated either as single applications or blocks of two consecutive applications with an unrelated fungicide partner, preferably fentin hydroxide because of its non-specific mode of action and low risk of resistance. Reduced rate tank-mix combinations of azoxystrobin and fentin hydroxide, or other unrelated fungicides may also effectively delay development of resistance to the strobilurins. However, there is insufficient data at this time to support the use of tank-mix combinations of azoxystrobin and further experimentation will be necessary to evaluate the effectiveness of various fungicide combinations.

Benzimidazoles. Benomyl and thiophanate methyl have not been recommended as stand-alone fungicides since benomyl resistance was reported in the pecan scab fungus in the mid-1970s. Although benzimidazoles are no longer recommended for scab control, they are still considered to be effective for control of zonate leafspot and powdery mildew. Management of benzimidazole resistance in these pathogens is based on limiting the number of applications, avoiding consecutive applications, and always incorporating fentin hydroxide at reduced rates in tank mixes (Ellis et al. 1998). Because cross-resistance is common among members of this fungicide group, both benomyl and thiophanate methyl can be considered identical with respect to resistance management. Therefore, an application of benomyl followed by an application of thiophanate methyl would be considered a consecutive application and would not be appropriate for resistance management.

Dodine. Although dodine resistance has not been reported in the pecan scab fungus, it is considered an at-risk fungicide and should never be used for full season disease control. Applications of dodine should be alternated with other non-related fungicides, preferably fentin hydroxide. Reduced rate tank-mix combinations with fentin hydroxide or other fungicides may also be effective for resistance management, but additional experimentation will be necessary before such tank-mix combinations can be recommended.

Assessing the Effectiveness of Resistance Management Programs

Fungicide sensitivity monitoring is an important component of a successful resistance management program. Data collected from sensitivity assays of fungal isolates sampled from treated orchards can be valuable for detecting shifts in the sensitivity distribution of a pathogen population before disease control is compromised. Sensitivity monitoring is also an important tool for assessing the effectiveness of resistant management programs. Fungicide sensitivity measurements are relative, and detection of resistant strains or populations must be based on a comparison with "wild-type" sensitive strains or populations. Hence, an essential first step in developing a monitoring program is the establishment of a so-called "baseline" sensitivity distribution for a specific pathogen-fungicide combination. Such baselines have been established for sensitivity of the pecan scab fungus to the DMIs propiconazole and fenbuconazole (Reynolds et al. 1997).

Sensitivity assays are usually based on traditional biological methods such as mycelial growth tests or spore germination tests in liquid or solid media amended with a range of concentrations of fungicide, or using in vivo assays conducted on inoculated host plants or leaf discs (Ishii 1995). In general, these biological assays are quite laborious and time-

consuming. The availability of a more rapid and efficient sensitivity assay would allow a much faster response time in the event of an imminent fungicide control failure. More rapid assays, based on DNA probe technology have been developed for detection of benzimidazole-resistant fungi (Ishii 1995). However this approach is only feasible if the molecular mechanism of pathogen resistance is well understood.

Future Outlook

Fungicides. Additional DMI and strobilurin compounds are currently under development for use on pecan. Cross-resistance between DMIs is common, therefore any new DMI fungicides registered for use on pecan in the future must be used with care to avoid resistance problems. The potential for cross-resistance between azoxystrobin and kresoxim-methyl, a new strobilurin fungicide currently under development, is unknown and must be evaluated before resistance management recommendations can be made (Ammerman et al. 1992). A new pecan fungicide with a non-specific mode of action and low risk of resistance would be highly desirable as a mixing partner for management of resistance to the DMIs and strobilurins. However, fungicides that are currently under development are more likely to be highly specific in their mode of action and at risk for development of resistance. An alternative would be to identify potential mixing partners with a completely different site-specific mode of action from those fungicide classes already in use. Changes in the availability of fungicides for disease control and resistance management also may occur through loss of registration of existing fungicides. This is a concern especially for older, more toxic fungicides such as fentin hydroxide. Loss of mixing partners with a non-specific mode of action and low risk of resistance could have a significant impact on resistance management programs for pecan.

Disease Management. Scab is likely to continue to be major target of fungicide application programs for pecan, especially in the southeastern states. Development of new approaches to scab control, based on weather conditions and/or forecasts, may lead to changes in the timing and frequency of fungicide applications that could have a significant impact on resistance management programs (Sparks 1995, Bertrand and Brenneman 1998, Driever et al. 1998).

Resistance management strategies. The relative merits of alternations versus mixtures for resistance management have been debated for many years. There is some evidence, based on theoretical models, that alternations are somewhat more effective than tank-mixes for delaying simultaneous development of multiple resistance to both fungicides (Shaw 1993). However, tank-mix combinations of appropriate fungicide partners, especially when sold exclusively as a pre-packaged combination, do provide a greater level of assurance that the fungicides are applied according to resistance management recommendations. Continued field evaluation of new combinations of fungicides, both in alternation and as tank mixes, is needed in order to provide sound resistance management recommendations.

Resistance Monitoring. Faster, more efficient techniques for sensitivity monitoring are needed to facilitate timely detection or warning of resistance problems and evaluation of resistance management programs. Rapid and efficient biotechnological techniques using DNA probes can be used to detect fungicide resistance once the mechanism of resistance has been determined at a molecular level. This approach has been successful for monitoring resistance to benzimidazoles, for which the genetic mechanisms of resistance are well understood (Ishii 1995). For DMIs, however, the mechanism of resistance in fungal pathogens is complex and poorly understood, making it difficult to utilize biotechnological methods for detection of resistance. The strobilurin fungicides are still so new that there is very little information available about the mechanisms of resistance. Much more research will be needed to elucidate the mechanisms and genetic control of resistance before application of this new technology can be fully exploited.

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SPRAY ADVISORIES FOR PECAN SCAB: RECENT DEVELOPMENTS IN GEORGIA

Tim Brenneman[1], Paul Bertrand[1] and Ben Mullinix[2]

ABSTRACT

Various attempts have been made to develop environmentally-based spray advisories for pecan scab. Currently most growers still use a calender schedule with some intuitive adjustments for extremely dry or wet weather. Two new models have been developed recently in Georgia and are being evaluated in both small plots and by growers. One model utilizes primarily leaf wetness periods and calls for sprays to be applied after a favorable infection period. This model relies on the post-infection activity of systemmic triazole fungicides. The second model, AU-Pecan, is an adaptation of the AU-Pnut advisory for peanut leafspot. This model uses the number of rain events in conjunction with the five day percent chance of rain. It requires only a rain gauge and a weather forecast to operate. AU-Pecan is the first model to incorporate a true forecasting component and thus enable growers to respond prior to scab-favorable conditions. Simulations with weather data from 15 years in Tifton indicate that an average of 3.9 sprays would have been applied annually compared to seven on a standard grower schedule. Further field testing is required to verify the effectiveness of these models and better define limitations due to delayed spray response, cultivar variability, different fungicide chemistries, etc.

INTRODUCTION

Pecan scab, caused by *Cladosporium caryigenum* (Ellis & Langl.) Gottwald, continues to be the most damaging disease of pecan in the southeastern United States. In Georgia the estimated losses to scab have averaged $1.6 million from 1993 to 1997. This varies widely from wet years like 1994 with heavier losses ($4.1million) to dry years like 1993 with negligible losses. However, even in dry years fungicides represent a major cost of production. Growers spend an average of $11.5 million annually for fungicides to control scab, and this cost is increasing due to higher prices for fungicides.

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Genetic resistance to pecan scab has been a priority for breeding programs, but the track record of success has not been great. In fact, experience has shown that cultivars with apparent resistance tend to become susceptible over time (Latham and Goff, 1991). Actually the cultivars do not change, but various strains of the pathogen exist (Converse, 1960), and they are able to change and adapt to new genotypes (Littrell & Bertrand, 1981). Other control measures include cultural practices such as pruning trees and cutting surrounding vegetation to improve air movement. While these may help reduce scab incidence, growers still rely heavily on fungicides for disease control.

The primary fungicide for scab is fentin hydroxide (Super Tin or TPTH) which has been used for over 30 years. Two triazoles, propiconazole (Orbit) and fenbuconazole (Enable), have been labeled for use on pecans and offer growers a systemmic alternative. Dodine is an older fungicide that is being used more recently due to availability of a competitively priced formulation. Other options include Ziram and Benlate but these are not widely used. The most recent addition is azoxystrobin (Abound) which is slowly systemmic and offers a totally different mode of action. These fungicides are generally applied on a calender schedule of three prepollination (2-week interval) and four postpollination sprays (3-week interval) with some adjustments made intuitively for weather extremes.

PECAN SCAB ADVISORIES

Several ways have been explored to reduce fungicide inputs. Reduced rates of TPTH have sometimes lead to higher disease and lower yields (T. B. Brenneman, unpublished data). Wells et al. (1976) tried using reduced numbers of sprays at double the normal use rates with mixed success. Terminating spray programs at shell hardening has been shown to have no impact on nut quality or yield (Gottwald and Bertrand, 1988).

Another way to maximize the benefit received from fungicides is to use them only during those periods of high humidity and warm temperatures favorable for infection by *C. caryigenum*. This idea has lead to the development of several models designed to identify those favorable infection periods, thus allowing growers to only spray when it is truly needed. Early forecasts used cumulative leaf-wetness hours as defined by 90% or greater relative humidity (Gazaway and McVay, 1980; Hunter et al. 1978) and

some tree growth parameters were later incorporated as well (Hunter and Payne, 1980). Variations of this resulted in spray savings during some years and up to 17 sprays during wet years (Gazaway and McVay, 1980; McVay and Gazaway, 1980; Miller et al. 1979). Although these models have not subsequently been used by growers, they did demonstrate the potential for optimizing benefits from fungicide inputs.

Recently there have been renewed efforts towards development of weather-based advisories in Georgia. In the late 1980's several grower trials were conducted to evaluate a model using 16 hours of continuous leaf wetness as a threshold for spraying (Hargrove et al. 1991). This model utilized propiconazole (Orbit) applied post-infection and allowed a 10 day protection interval after application. Six of the eight experimental plots had equal or better scab control with the same or fewer applications than calender programs. Dr. Darrell Sparks (Sparks, HortTechnology 1995) then published a model that was also based on continuous leaf wetness periods (8 hours) and the curative control available with systemmic fungicides applied after a rain event. Some growers have tried this model and it needs to be evaluated under a wider range of conditions.

Another model under development in Georgia has been derived from the Au-Pnuts advisory for late leafspot (*Cercosporidium personatum*) in peanuts (Davis et al., 1994; Jacobi et al. 1995). In terms of epidemiology and control measures there are many similarities between the two diseases. Brenneman and Bertrand have modified Au-Pnut to accomodate differences due to pecan phenology and called it AU-Pecan. For example, a default spray at parachute stage is called for to ensure protection of the very susceptible young foliage and all sprays are terminated at shell hardening since scab occurring later in the year has been shown to not affect yield or quality (Gottwald & Bertrand, 1988). Also, the protection intervals utilized after each application are shorter for the prepollination than for the postpollination sprays.

FIELD TRIALS

Both the AU-Pecan model and the Sparks advisory were tested in 1997 at the Coastal Plain Experiment Station Ponder Farm and at Luke Orchards in Berrien County. The Sparks advisory was actually modified to utilize a threshold of 12 consecutive hours of leaf wetness, a compromise between the original model and the Hargrove model (1991) using 16 hours . Leaf wetness was monitored continuously every 15

minutes by on-site weather stations (Agricultural and Meterological Systems, Inc., Middlesex, NC) using 98% RH as a measure of leaf wetness. Weather stations also monitored rainfall which, in addition to the 5-day percent chance of rain, was used to drive the AU-Pecan model. The 5-day percent chance of rain was supplied by the Agricultural Weather Information Service, Auburn, AL. The Tifton site had both Desirable and Wichita trees whereas the Luke Orchard had only Desirable trees. The fungicide program in both trials was the Orbit 45W (0.25 lb/A)/Super Tin 80W (5.0 oz/A) co-pack. Treatments were replicated four times at both sites and all sprays were applied with commercial air-blast sprayers.

At the Tifton site eight sprays were applied according to the calender schedule versus six and five with the AU-Pecan and Sparks advisories, respectively (Table 4). At the Luke Orchard, 10 sprays were applied according to the calender schedule versus 8 and 6 with the AU-Pecan and Sparks advisories, respectively (Table 4). Pecan scab was not severe in 1997 due to relatively dry conditions. At Tifton, nontreated Desirables had only 10% scab severity on nuts as of Oct. 1 (Table 1). All treatments reduced foliar and nut scab disease severity compared to the nontreated trees, but there were no differences between treatments. Wichita had much higher disease levels with a nut scab severity of 95% as of Oct. 1 (Table 2). All treatments were significantly better than the nontreated control for both foliar and nut scab. The Sparks advisory did have significantly higher nut scab than the other treatments, but this was not reflected in yields (Table 2). At the Luke Orchard, there were no differences among fungicide programs in regard to foliar or nut scab or nut quality parameters (Table 3).

ADVISORY SIMULATION DATA

To better understand and predict the performance of spray advisories in Georgia, 15 years of weather data from Tifton were analyzed (1983-1997). Actual rainfall was used and assumed to be a 100% accurate forecast for the next five days. We also assumed that budbreak was on April 1 of each year and that pollination occurred on May 15 for the purpose of separating prepollination (PRE) and postpollination (POST) spray intervals. Shell hardening was assumed to occur on August 15 and no sprays were applied after that date. Additionally, any spray called for on a day with ≥ 1 inch of rain would be postponed to the next dry day. The standard AU-Pecan model was evaluated along with several modifications and scenarios where sprays were

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delayed beyond the advised spray dates. These variations are listed in Table 5 along with several calender spray schedules. An average of 7.0 and 9.7 sprays would have been applied using a calender schedule with a 14/21day or a 14/14 day PRE/POST interval, respectively. The basic AU-Pecan model uses a 10/14 day PRE/POST protection interval and a default spray at the parachute stage if a spray has not already been applied. This model (trt. #1, Table 5) called for an average of only 3.9 sprays per year from 1983-1997. Spray numbers ranged from a low of only one during the very dry year of 1986 to a high of seven during 1991. If the default spray at the parachute stage were eliminated from the model, the number of sprays dropped to only 3.0 annually (trt. #10, Table 5). Changing the protection intervals to either 10/11 days PRE/POST or even 12/17 days PRE/POST had very little impact on the average number of sprays applied annually. Similarly, a consistent two day delay in spraying had little impact on spray numbers, but a four day delay reduced average spray numbers by about 0.5 sparays per year. Of course the impact of such delays on disease control is not known.

DISCUSSION

The most pressing need at this time is for replicated field data to verify the performance of these models under "real world" conditions. Simulations such as those reported here are useful, but are no substitute for actual field trials. Also, the assumptions made with some of the models in use are based on greenhouse studies where plants were sprayed to runoff with a hand sprayer. Tests we have conducted in Tifton indicate that this method greatly overestimates fungicide deposition when compared to field applications with an airblast sprayer. This may result in misleading conclusions regarding basic efficacy as well as curative or post-infection activity. Recent studies by Dr. Chuck Reilly comparing hand-sprayed versus airblast sprayer applied treatments give reason to doubt the reality of extended curative activity under field conditions. Since most growers are not able to immediately spray their entire orchard on every advised spray, this question is critical in helping them know how to use this system. In fact, some growers should not even attempt to use an advisory because they do not have adequate equipment to spray in a timely fashion.

With the limited data available, the Sparks advisory and the AU-Pecan advisory seem to give similar end results. The Sparks model may tend to call for fewer sprays, but it should be noted that we were using a 12 hour rather than an eight hour wetness period as a

threshold. Using an eight hour threshold would undoubtedly have been more conservative and called for additional sprays. One advantage of the AU-Pecan model is that it is more of a true forecast since it utilizes the five day weather forecast and does not rely strictly on events that have already occurred. This allows a grower to spray ahead of advancing weather fronts. It should also be noted that the manufacturers of DMI fungicides such as Orbit and Enable specifically request that there products not be used as post-infection treatments due to the increased risk of fungicide resistance.

We also need to know more about other aspects of these advisories. How do other fungicides such as the new methoxy acrylates (Abound) perform with predictive models versus calender sprays? What effect does cultivar susceptibility have on the models? It may be beneficial to incorporate several layers of risk into the model. This would allow growers to select the level of risk they are comfortable with and tailor programs to individual orchards. Research is underway to try and answer these and other questions.

Many pecan growers are experiencing economic hardships related to rising production costs, uncertain prices, and erratic production. There is an urgent need for technology to reduce the cost of production, and pecan scab advisories certainly have that potential. For example, in our 1997 test on Desirables in Tifton, unsprayed trees sustained nut scab severity of only 10%. Applying seven or eight fungicides to these trees would have been a waste of money. With focused research efforts and cooperation of growers we should be able to make great progress in this area.

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Table 1. Evaluation of two spray advisories and a calender schedule for control of pecan scab on Desirable trees, Ponder Farm, CPES, 1997 [1]

| Fungicide Schedule | # of Sprays | Nut Scab | | Leaf Scab | Nuts per |
		Incidence 8/19	Severity 10/1	Incidence 6/2	Pound
1. AU-Pecan	6	9.7	0.0	0.7	49.8
2. Sparks Model	5	13.5	0.3	0.3	49.1
3. Calender	8	7.6	0.1	0.0	47.8
4. Nontreated	0	77.4	10.0	5.1	49.7
LSD (P≤0.05)		15.5	1.1	2.9	N. S.

[1] The fungicide program used for all treatments was Orbit 45WP (0.25 lb/A) + Super Tin 80WP (5.0 oz/A).

Table 2. Evaluation of two spray advisories and a calender schedule for control of pecan scab on Wichita trees, Ponder Farm, CPES, 1997[1]

| Fungicide Schedule | # of Sprays | Nut Scab | | Leaf Scab | Nuts per |
		Incidence 8/19	Severity 10/1	Incidence 6/2	Pound
1. AU-Pecan	6	100.0	31.4	21.4	74.1
2. Sparks Model	5	100.0	50.0	21.9	78.3
3. Calender	8	100.0	27.1	29.2	83.9
4. Nontreated	0	100.0	95.3	70.4	105.5
LSD (P≤0.05)		N. S.	12.6	10.3	17.0

[1] The fungicide program used for all treatments was Orbit 45WP (0.25 lb/A) + Super Tin 80WP (5.0 oz/A).

Table 3. Evaluation of two spray advisories and a calender schedule for control of pecan scab on Desirable trees, Luke Orchard, 1997[1]

Fungicide Schedule	# of Sprays	Nut Scab Severity		Leaf Scab Incidence	Nuts per Pound
		7/25	8/20		
1. AU-Pecan	7	0.6	3.8	7.4	52.8
2. Sparks Model	6	1.5	7.1	11.0	55.4
3. Calender	9	0.8	5.7	7.2	52.3
4. Nontreated	0	10.8	43.0	35.2	82.0
LSD (P≤0.05)		2.1	4.2	7.9	7.0

[1] The fungicide program used for all treatments was Orbit 45WP (0.25 lb/A) + Super Tin 80WP (5.0 oz/A).

Table 4. Actual spray dates for advisory and calender treatments in 1997 and 1998 field tests.

Test and Treatment	Spray Number									
	1	2	3	4	5	6	7	8	9	10
Ponder Farm, 1997										
AU-Pecan	4/2	4/24	5/20	6/12	7/2	7/30				
Sparks Model 4/2	4/24	5/24	6/12	7/30						
Calender	4/2	4/15	4/30	5/21	6/11	7/1	7/23	8/12		
Luke Orchard, 1997										
AU-Pecan	4/1	4/15	4/30	5/29	6/20	7/9	7/28	8/17		
Sparks Model 4/1	4/30	5/29	6/20	7/9	7/28					
Calender	4/1	4/15	4/30	5/15	5/29	6/11	6/24	7/9	7/23	8/7
Ponder Farm, 1998										
AU-Pecan	4/10	4/30	5/1		To be determined!					
Sparks Model 4/10	4/30	4/29		To be determined!						
Calender	4/6	4/21	5/4	5/25	To be determined!					

Table 5. Simulated spray applications determined from historical environmental data, Tifton, GA (1983-1997).

| Year | Calender | | | AU-Pecan Variations* | | | | | | | | | |
	14/21	14/14	10/14	1	2	3	4	5	6	7	8	9	10
1983	7	10	10	5	5	4	5	5	4	5	4	4	5
1984	7	10	10	5	5	4	5	5	5	5	4	4	4
1985	7	10	10	2	2	2	2	2	2	2	2	2	1
1986	7	10	10	1	1	1	1	1	1	1	1	1	0
1987	7	9	10	5	5	4	5	5	5	5	5	4	4
1988	7	9	10	3	3	2	3	3	2	3	3	2	2
1989	7	9	10	5	5	5	5	5	5	5	5	4	4
1990	7	10	10	2	2	2	2	2	2	2	2	2	1
1991	7	10	10	7	7	6	7	7	7	7	6	5	6
1992	7	9	10	4	4	3	5	4	3	4	4	3	3
1993	7	10	10	3	3	3	3	3	3	3	3	3	3
1994	7	10	10	6	6	4	6	6	5	5	5	4	6
1995	7	10	10	3	3	3	3	3	3	3	3	3	2
1996	7	10	10	3	3	3	3	3	3	3	3	3	2
1997	7	10	10	4	4	4	5	5	4	4	4	4	3
Avg.	7.0	9.7	10.0	3.9	3.9	3.3	4.0	3.9	3.6	3.8	3.6	3.2	3.0

* Variations of the AU-Pecan model were validated assuming for each year that bud break was April 1, pollination was May 15, and sprays were terminated on August 15 at shell hardening. Specifics regarding prepollination (PRE) and postpollination (POST) protection intervals and other varibles are as follows:

Model	PRE/POST Protection Interval	Default Spray at Parachute Stage?	Days of Delay After a Favorable Advisory
1.	10/14	Yes	0
2.	10/14	Yes	2
3.	10/14	Yes	4
4.	10/11	Yes	0
5.	10/11	Yes	2
6.	10/11	Yes	4
7.	12/17	Yes	0
8.	12/17	Yes	2
9.	12/17	Yes	4
10.	10/14	No	0

PECAN SCAB MANAGEMENT: A PREDICTIVE MODEL FOR OKLAHOMA

S. L. von Broembsen[1], G. F. Driever[1], M. W. Smith[2], J. A. Duthie[1], and J. D. Carlson[3]

ABSTRACT

The Oklahoma Pecan Scab Model was developed from epidemiological studies at several field sites in Oklahoma during 1993-1996. The model predicts that pecan scab will develop within seven to fourteen days once a threshold level of scab favorable hours accumulates within the last fourteen days, unless intervention with fungicides takes place. The model sets different thresholds for moderately and highly susceptible cultivars. The Oklahoma Pecan Scab Model uses weather data from the Oklahoma Mesonet system of 111 weather stations located throughout the state of Oklahoma. Temperature and relative humidity data are automatically radioed to a centralized computer where computer programs process this information daily to produce outputs for each of the locations. Growers and advisors can obtain local predictions by accessing the web site and using a clickable map to select the desired location. This information can then be used to decide when to apply fungicides. The model is in the second year of validation and refinement.

INTRODUCTION

Pecan scab caused by the fungal pathogen *Cladosporium caryigenum* (Ell. et Lang.) Gottwald is a limiting factor in pecan (*Carya illinoensis* Koch.) production in the Oklahoma. The fungus overwinters on twigs and ground debris and each spring begins polycyclic infection of leaves, twigs, and fruits of the pecan. Pecan scab is managed using a combination of plant resistance, cultural practices and fungicides. Recommendations for scheduling fungicide applications have been based on calendar or phenological schedules. The full calendar schedule

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set out on fungicide labels certainly provides excellent control, but in Oklahoma also results in about twice as many applications as are needed to control the disease. Another method of scheduling fungicide applications, which uses developmental stages of the pecan to schedule spray applications, has been developed in Oklahoma. This phenological method has proved effective and economical for native pecans, for which a maximum of three applications per season beginning once pollination is complete, are sufficient. However for moderately to highly susceptible cultivars, fungicide programs usually need to begin earlier and to have more applications to get good control. Clearly a better system of scheduling fungicides for these types of pecan was needed. Ideally this decision system should result in fungicides being applied when and only when needed, eliminating unnecessary applications but providing effective control.

We decided to develop a model that was able to forecast or predict when disease would occur based on the occurrence of weather conditions favoring disease development. This goal acknowledged the need to make decisions about fungicide applications that were specific for local weather conditions.

EPIDEMIOLOGICAL STUDIES AND THE PROTOTYPE MODEL

During 1993 an epidemiological study on unsprayed trees was undertaken at the Oklahoma State University Pecan Research Station near Sparks, Oklahoma to measure the development of scab as related to weather (Marenco 1994). Weekly disease ratings using the modified Horsfall-Barratt rating scale (Horsfall and Barratt 1945) were taken on tagged leaves and fruits of native pecans and a highly susceptible cultivar, 'San Saba Improved'. Weather data (temperature, relative humidity, leaf wetness, and rainfall) was recorded hourly by an on-site data logger and was retrieved weekly and compiled into data files. In 1994 similar studies were conducted at that site as well as two additional sites (the Noble Foundation Red River Research and Demonstration Farm near Burneyville, OK and at Little Cabin Pecan Orchard near Vinita, OK). These three studies were repeated again in 1995 (Driever 1998).

In early 1996 the epidemiological and weather data from these studies were compared and trends were assessed for specific weather conditions and the increase of disease. An empirically derived, prototype threshold model was developed for testing during the 1996 growing season. This prototype

model was tested at the Sparks site on the highly susceptible cultivar 'Western' and at Knight's Pecan Farm near Sapulpa, OK on the moderately susceptible 'Pawnee' cultivar. Scheduling of the threshold treatment in the trial was based on the continual accumulation of hours with temperature and relative humidity favorable to scab until the threshold was reached. The threshold scheduling was compared with a calendar schedule (six applications) and a phenological schedule (four applications). For this trial, the accumulation of hours of scab favorable weather was calculated manually each day. At both sites the threshold scheduling was effective in limiting scab infection with fewer applications (Driever, 1998). However, a higher incidence of disease occurred on the highly susceptible 'Western' fruits than was considered to be acceptable. This highlighted the need to develop a model based on a complete analysis of the epidemiological and weather data.

DEVELOPMENT AND TESTING OF THE OKLAHOMA PECAN SCAB MODEL

In the latter part of 1996 statistical analyses were conducted to determine the correlation of weather data from in-field data loggers with that obtained from weather stations of the Oklahoma Mesonet system. These analyses yielded a very high correlation between these two types of weather monitoring sites and showed that nearby Mesonet sites (no further than 15 miles away) could be used instead of on-site data loggers as weather monitoring devices for the forecasting model.

Extensive regression analyses using SAS were conducted on the 1994 and 1995 data to compare disease rating changes with various types of the Mesonet weather data over time. The analyses showed that the highest correlation between change in disease ratings and weather data was for hours when temperature ≥ 21.1 C (70 F) and relative humidity $\geq 90\%$. Preliminary analysis of the size of units of weather had shown that one hour was the minimum time unit for correlation with disease development and was equal to or better than any larger unit. For purposes of further analysis and subsequent modeling, an hour with the average relative humidity $\geq 90\%$ and the average temperature ≥ 21.1 C (70 F) was defined as a scab hour.

Regression analysis was carried out for scab hours occurring within moving intervals of time (2, 7, 14, and 21days) preceding a selected point in time and change in disease rating. These analyses showed that

the most highly correlated period for occurrence of scab hours with disease rating change was 14 to 28 days preceding the end of a seven day rating period.

With the scab favorable weather criteria and prediction period established, we proceeded to set thresholds of scab hours accumulated in the last fourteen days for the two levels of cultivar susceptibility included in our trials. Table Curve (AISN Software) was used to determine the equations that best fit the data correlating accumulation of scab hours and increase in disease rating on fruits throughout a season for both the highly susceptible and the moderately susceptible cultivars. Deciding that disease on fruits should be limited to a 0.5 rating change on the Horsfall-Barratt scale during a vulnerable period and that a final rating should not exceed a rating of 3 (maximum 25% disease), thresholds were determined from graphs of the appropriate equations. These thresholds were set at 30 scab hours accumulated within the last 14 unprotected days for moderately susceptible cultivars and at 10 scab hours accumulated within the last 14 unprotected days for highly susceptible cultivars.

During 1997, both the 10 and 30 hour thresholds were tested against the phenological schedule on 'Western' at the Sparks site using the model. The model scheduling took into account whether fungicides had been applied and assumed a fourteen day protection period following fungicide application. A tank mix of half rates of Enable and Super Tin was used so that the confounding effect of different fungicides at different times would be avoided. The 10 hour threshold scheduling was as effective as the phenological scheduling with one less fungicide application (three and four applications respectively) on this highly susceptible cultivar. Both treatments gave very acceptable (as defined by the model goals) levels of disease control on fruits. We are currently conducting a trial on the moderately susceptible cultivar 'Pawnee' to fine tune the threshold for this level of scab susceptibility.

INTERNET DELIVERY OF THE OKLAHOMA PECAN SCAB MODEL

During March 1997 the Oklahoma Pecan Scab Model was set up to operate from an Internet site: **www.okstate.edu/~mesonet/scab/** (Fig. 1). The Oklahoma Pecan Scab Model uses weather data from the Oklahoma Mesonet system of 111 weather stations located throughout the state of Oklahoma. Temperature and relative humidity data are automatically radioed to a centralized computer

where programs process this information daily to produce outputs for each of the locations. The model's thresholds are based on the accumulation of scab hours, and on the assumption already stated that disease should not exceed a final rating of 3 on the Horsfall-Barratt scale. The model also calculates in a fourteen day protection period following any fungicide application.

Growers and advisors can obtain the current local accumulation of scab hours toward thresholds by accessing the web site and using a clickable map to select the desired location. The web site displays the total number of accumulated scab hours for the last 14 unprotected days, a statement and explanation of the model thresholds in scab hours for both highly susceptible and moderately susceptible cultivars, and the number of scab favorable hours that occurred during each of the last 28 days. This information can then be used to decide when to apply fungicides. The web site also links to important information such as fungicide products and rates, susceptibility of pecan cultivars, and other scab management practices.

We are continuing to test the model in the field to refine the thresholds for different levels of susceptibility and are expanding the information that can be accessed from the web site.

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Figure 1. Home page of the Oklahoma Pecan Scab Model showing the interactive map that an Internet user can use to select the site nearest their pecan orchard. An intermediate page then asks for the last date fungicides were applied. If no date is given, a default of April 1 is used. The program then calculates the number of 'scab hours' that have accumulated in the last 14 unprotected days. In addition, the 'scab hours' for each of the last 28 days are listed by date.

OKLAHOMA PECAN SCAB MODEL

OKLAHOMA STATE UNIVERSITY
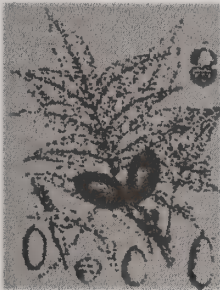
The Pecan Scab Model for scheduling fungicides is based on field studies conducted at four sites in Oklahoma over the past four years. It calculates the hours with temperature and moisture conditions favorable for infection and disease development. The model lets you know when to spray to protect your pecans but it also indicates when it is unnecessary to spray. Growers should be aware that the model is still in the development stage, but we hope that you will find the information useful.

The map below shows the location of 111 automated weather stations from the Oklahoma Mesonet. To use the model you must first select the Mesonet station nearest to your pecan grove so that the model can use weather data that is most applicable for you. You will also need to know the date that you last applied the fungicide for scab, so have that in mind. .

Click on the Station of interest

THE OKLAHOMA MESONET
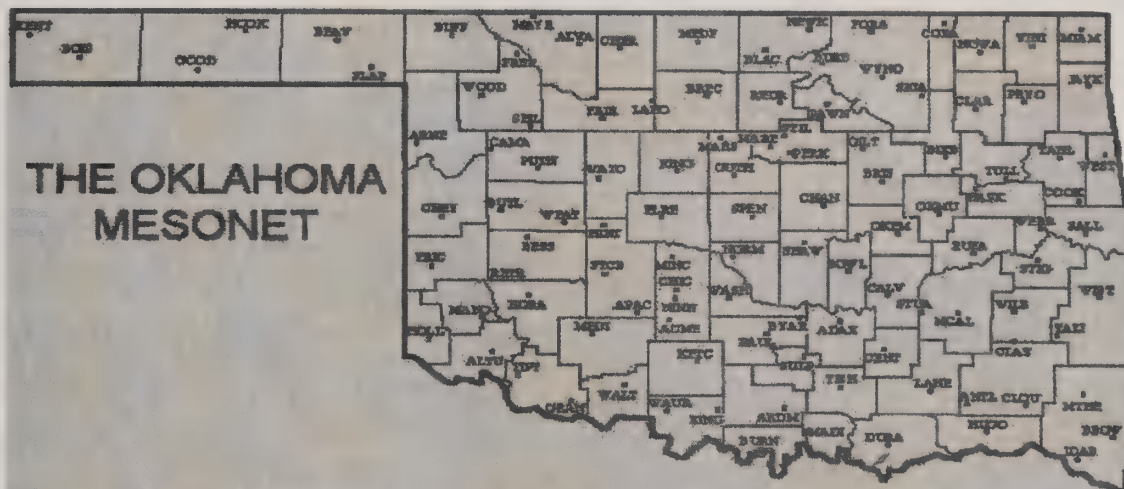
Warning: Click on the name for accurate connection. Clicking elsewhere will take you to the warning page.

Send mail to Sharon L. von Broembsen for all questions regarding the Pecan Scab Model.

This page has been accessed   times since 01/01/1997.

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MARKETING PECANS: PREPARING A MARKETING PLAN

Jose G. Peña and Larry A. Stein[1]

Crucial issues facing the pecan industry are the economic aspects of pecan production and markets as indicated by the complete market collapse during two of the last five years and just a marginal recovery during the 97/98 season.

While producers have traditionally done an outstanding job of producing pecans, they have often neglected marketing. The functions of management include the management of human resources, a financial management aspect, a production aspect and a marketing program. In terms of marketing, the pecan industry continues to "sell" pecans instead of "market" pecans.

The importance of marketing discipline and the need to have a written marketing plan is presented in this paper.

Having a good marketing plan will help producers identify and quantify costs, establish pricing goals, evaluate potential price outlook, analyze production and price risk, and help develop a strategy to market products to help achieve goals and objectives. In the past, more stable markets allowed producers to neglect or ignore the marketing side of their business. Now, with the increased volatility in the markets, producers will have the obligation to determine their own financial security. In this more uncertain/risk future, failing to plan may well be the same thing as planning to fail.

A marketing plan needs to be written down. A plan not written down is only a dream we wish would come true. Conversely, the plan must be dynamic. As external market factors change, the marketing plan may need to be adjusted. Having a written plan also provides discipline and a good way to check the logic or accuracy of the planning rationale after the year has ended. By putting the plan in writing, especially sharing it with a spouse, partners, etc., it will serve as a reminder of a commitment to follow a specific plan of action, such as selling a certain percent of the crop pre-harvest if prices reached (x) percent over the cost of production.

A brief review of the current pecan situation will serve as the basis for the need to prepare detailed marketing plans.

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TREE NUT TRENDS

Graph 1 provides a summary of improved and native pecan production in the U.S. together with average prices received (in-shell) from 1980 through 1997. A quick review of production and prices during the last eight years compared to the previous ten years indicates a return to wide production swings, higher uncertainty of the availability of pecans and the resultant wide price swings where the market collapsed during two of the last five seasons. Although prices prior to 1990 were lower, they were more stable. Prices reached record highs during the early 90's but have trended downward since then. During the last four years, price peaks for improved varieties have averaged $1.08/lb with average bottoms at about $0.70/lb. As a result, the market appears to be offering a window of opportunity of $0.70-$1.08/lb for improved varieties and about $0.30/lb lower on both sides of the window for native or seedling varieties. The marketing plan should focus within this window of opportunity and prepare plans to help capture opportunities above this window.

A more detailed comparative analysis of these two periods reveals the following:
- ☐ The current average crop size is down 25% from average production in the 80's
- ☐ The current average value of the crop is up 16% from the average value in the 80's
- ☐ The price of pecan meats is up 26% from the average price of meats in the 80's
- ☐ The average use (take off) is down 11% from average use levels in the 80's
- ☐ Carry-over stocks are trending up

When compared to the closest competitive tree nut, a similar analysis of walnut production reveals the following:
- ☐ Walnut acreage is down from the 80's
- ☐ The average value of the crop is up 22% when compared to the 80's
- ☐ Average production is down 6% when compared to the 80's
- ☐ Average price for walnuts is up slightly when compared to the 80's
- ☐ Average use is down 3% when compared to use during the 80's
- ☐

The primary differences between these widely contrasting indicators appear to be that when U.S. walnut production started to increase significantly, producers organized marketing associations, established marketing boards and prepared marketing rules. These actions appear to have encouraged producers and the industry to prepare marketing plans.

As a result it becomes imperative that pecan orchard owners and managers add a detailed marketing plan to their operations.

PLANNING

Planning is simply charting a course from where one is to where one wants to go. The procedures and techniques involve the logical formulation of a blueprint or guide to achieve selected goals that have been set for the business. As a result, the purpose of planning, given specific goals and resource limitations (real or self-imposed), is to select a combination of alternatives that maximizes utility (usually income) from the resource (orchard production) over a given planning horizon.

Goals and objectives should be written down and broken out by time category (1 year, 5 years, 10 years, etc.), so as to provide short, intermediate and long term direction to a plan. However, as mentioned earlier, a plan not written down, may be just a dream. Having a written plan provides a road map to work from. It helps identify where the operation is going and how it will get there. Each marketing year is similar to previous years, but new, different unencountered challenges usually appear each year. A written road map is essential to help maintain perspective and stay on coarse.

MARKET PLAN

The marketing plan must be dynamic and may need to change as market forces and outlook expectations change during the year. Having the original plan and the changes in writing allows post analysis of decisions and the thought process which influenced those decisions. This post plan review helps identify what was done correctly, but more importantly, can help determine where analysis, strategies, or discipline have room for improvement. This is one of the most critical reasons for having a written plan. Mistakes cannot be fixed until they are clearly identified. Without a written record, it may be difficult to identify what really went wrong.

A marketing plan should include the following parts:
☐ Analysis of Financial Condition and Statement of Goals:
☐ Price Goals and Price Risk Tools/Alternatives (Available)
☐ Market Outlook/Expectations
☐ Marketing Alternatives (Available)
☐ Price and Date Objectives
☐ Strategies

FINANCIAL SITUATION AND GOALS

The first step in preparing a marketing plan is to review the financial situation, and the goals and objectives for the operation. A review of the financial health of the operation (financial statement, debt load, non-farm income etc.) will provide an initial idea of the amount of risk the operation can bear. In addition to the financial situation, goals and objectives, personal risk preference, age, etc. will all influence the decision of alternatives available, i.e. input levels, varieties to separate for value added opportunities, marketing schemes, expansion or draw down plans etc. This initial assessment will help identify areas of risk, management tools which may be available, and how much risk, management may want to accept or avoid. In some cases, lender requirements may be an over-riding factor.

PRICE GOALS AND PRICE RISK TOOLS

The second step in preparing a marketing plan is to determine what price is needed to accomplished desired goals and objectives. This is often referred to as a break-even price. Often, a break-even price is calculated which covers production and harvesting expenses. As one economist put it, "You can go broke breaking even." You must calculate the price necessary to fulfill goals and objectives. These goals need to include gaining enough income to pay production expenses, meet debt obligations, provide ample income for cash flow, and possibly provide capital in order to build operator equity. Additional goals may include generating sufficient income to send a son or daughter to college or purchasing a new piece of machinery.

A review of break-even production costs appears appropriate.

A survey of pecan producers in central Texas indicates that break-even production costs approximate $0.76/lb to recapture variable operating expenses and $1.18/lb to recapture total expenses, including cash and non-cash overhead expenses (See table 1). Comparing these break-even estimates to the window of what the market has offered since 1993 indicates that whereas the market has allowed the clearance of variable expenses in the short term, the market window has not offered a sufficient price to operate in the long term, if operators are depending on traditional wholesale outlets for a large portion of their production.

Since yields and input levels are highly variable, depending on the producer, the region, the production environment and a multitude of other factors, table 2 provides a sensitivity analysis of the results of the cost production summary in table 1, by varying the yields (adjusted for harvesting costs).

A similar estimate should be prepared in the marketing plan based on specific financial records available.

Sensitivity analysis should be conducted at this point to see how much a 5, 10, or 20 percent change in yields will affect break-even prices.

Remember, you should add additional income requirements to the break-even price calculations to meet goals and objectives. For example, say you are operating a 500 acre orchard with average yields of 1,200 lbs/acre and your income objective is a family withdrawal of $50,000 for this coming year. In this example, $0.083/lb should be added to the per pound break-even price ($50,000 divided by (500 acres times 1,200 pounds)).

You may also want to add a reasonable expected return for the investment and/or an amount which would allow for growth or improvement. For example, assume that you have a total of $750,000 dollars invested in the 500 acre orchard ($1,500/ac) and the goal statement includes a five percent rate of a return target for the investment. In this example, an additional $0.063/lb should be added to the per pound break-even price (($750,000 divided by (500 acres times 1,200 lbs)).

Based on the review of what the market is offering above, these total price objectives may not be feasible.

If this was the case, the most obvious alternative would be to switch to crops which cost less to produce. This alternative is not possible for producers of perennial crops, such as pecans. What may be possible is to carefully evaluate all inputs and attempt to reduce and streamline their use and/or examine production systems closely in an attempt to increase production per unit while keeping input costs constant.

If, for example, the orchard includes the continued management of low producing sections such as areas with old varieties, shallow soils, or which are heavily shaded or a multitude of other reasons, it may become necessary to abandon or re-work those areas.

Other cost cutting or yield increasing alternatives should be identified. For example, crop load management may be a good way to reduce harvesting costs. Crop load management includes an assessment of the crop load by tree and shaking trees or branches with excessive loads during the middle of the summer to reduce the number of nuts. If performed correctly, this procedure can improve quality and reduce potential stick-tights and preharvest germination quality problems. This, inturn, translates to reduced cleaning and/or labor costs as it takes a tremendous amount of hand labor to remove these poor quality nuts. Reducing the nut load will

bring the load in balance with the leaf area servicing the load and not only improve quality but improve the chance of a return fruit set the next year. Eventually this tool could be used to reduce the swings in nut production from year to year.

Inconsistent production makes for a long season and inhibits a producer's ability to meet debt obligation.

Once a price objective has been established, markets, market shares and options available can be identified. A review of existing forward pricing opportunities and market outlook projections will help identify which alternative(s) may look more profitable or less risky during the coming year. Needless to say, if the calculated price objective is significantly higher than what the market is offering, the firm's plan must be completely reviewed. Perhaps its time to expand or draw-down. Standing still, hoping for a miracle may be disastrous.

MARKET OUTLOOK

A third component of the marketing plan is to assess the market situation and determine what might happen to prices as you progress through a production and marketing year. While a precise price forecast into the future may not be possible with much accuracy, a close examination of markets, marketing trends and alternative market pricing opportunities may provide some idea of the probability that the market will offer a price that will meet your objectives some time during a marketing cycle.

Knowing how markets typically act and the possibility of them doing something different in the future can help in developing a market strategy. Most commodity prices are seasonal. Seldom will the highest price for a seasonally produced commodity occur when harvest is in process, but it does occasionally happen in short crop years.

Some of the highest prices and best pricing opportunities in the pecan industry have occurred as the new crop harvest begins as was the case during this past season.

How do you expect the market to act this year? Supply and demand for pecans is heavily influenced by economic conditions in the 15 Southern states where pecans are produced. Less than 20% of U.S. pecan production is exported. A build up of carry-over stocks and imports are also having a big influence on the market. Factors expected to influence prices should be carefully studied and written into the marketing plans. Relevant market factors could include current US.

ending stock levels, projected consumption and exports, growing conditions in the U.S. and similar information covering the major competitive tree nuts such as almonds and walnuts. Again, remember that a marketing plan must be dynamic. As conditions change, incorporate the changes into the marketing plan.

As mentioned above, the trend is toward a build-up of carry-over stocks. Traditionally, in September when the new crop starts to trickle in, carry-over stocks continue to decline during the heavy pre-holiday demand period until about the end of November. When the harvest peaks, stocks begin to build-up until around February. Thereafter carry-over stocks begin to decline as the harvest is complete and usage reverts to out of storage stocks. Marketing opportunities appear feasible within this historical market cycle, if planned properly.

This year, carry-over stocks into the 98/99 season are higher than last year and may influence new crop prices. Related to this would be the influencing status of carry-over stocks from competitive tree nuts such as walnuts and almonds.

MARKETING ALTERNATIVES

A fourth component of the marketing plan is to know what marketing alternatives are available. A word of caution, it is not an alternative if sufficient information is not available to implement that alternative. Producers have an array of marketing alternatives in their arsenal, yet many are content to sell their commodity at harvest or shortly thereafter. This may be a result of tradition, lack of knowledge of alternatives or the absence of adequate storage facilities. Needless to say, current necessity dictates that producers will have to explore, learn, and select alternatives. Examples of these alternatives may include such things as a careful separation of the crop based on quality grades of one to five with five being the lowest quality, separation of varieties with a high direct appeal such as easy to shell, attempts to capture part of the increased demand for high quality new crop pecans during the pre-holiday season, early harvesting plans which may include partial green harvest, identification of direct marketing opportunities, consignment sales where pecans are exposed to new markets and/or used as attractants by retail shops and focusing on diverging consumer preferences for pecans such as in-shell, cracked, halfs, pieces and even end product preparation such as seasonal candies. A higher weighted average blend price than traditional bulk wholesale prices offered by the market may be possible by capturing as much of the value added market as may be economically feasible.

Each alternative has advantages and disadvantages such

as the additional costs of adding a new marketing scheme. Alternatives should be analyzed to evaluate the additional profit potential.

The use of forward contracts based on the point systems have started to appear as early as mid-summer. Shellers and end users with large plants want an assurance of a steady supply of pecans to keep their plants and products flowing. Many producers are reluctant to forward contract their pecans because of production and price uncertainties. Once the commodity is priced through a forward contract, the risk is that price will move higher. This is a disadvantage of forward contracting, however, if the negotiated forward price meets the price objectives of the producer, risk has been compensated for and one should not be disappointed if prices move higher.

PRICE AND DATE OBJECTIVES

In this section of the marketing plan, the information from the previous sections (cash flow needs, costs, price objectives, outlook, production and price risk tools) may be combined to help in identifying price and date triggers. By what date would you like to have some pre-harvest sales made? What price would you need pre-harvest versus what price would you need or accept post-harvest, i.e. what are the storage costs and how much per pound will storage costs add to the break-even price? Will the additional cost clear the market? Are there some seasonal price tendencies that you want to try to take advantage of?

STRATEGIES

Probably the most difficult yet most important component of the marketing plan is determining a way to combine all of your information into an overall strategy to follow. This requires discipline, and takes into account all the previous information such as the expected production, break-even price, and market outlook, etc. You need to have a plan that covers what to do if prices rise, but also, what to do if prices decline.

As an example, consider your up-coming crop. You may choose to scale up sales, selling ten percent increments of expected production at increasingly higher price levels. At what price would the first portion of the crop be priced? What tool would you choose to price the crop? What if, by November or the peak of the harvest for a given region, prices have only reached 80-90% of your target and the total U.S. crop looks good, i.e. prices would be expected to fall? How much would you have priced using any tool available? What will you do if prices decline to your break-even and you have not priced any of the crop yet? Even if

you think prices will go higher, how much downside protection do you need? How will you provide downside protection; keep in mind that you must provide a means for downside protection while leaving the upside potential completely open?

Special sales strategy and techniques should be included in this section, such as product identification, etc. For example, the recent U.S. Surgeon General's report indicated that five out of the ten leading causes of premature deaths are related to diet. Research scientist have proved that pecans are healthy to your diet. With just minor amounts consumed daily, they reduce the level of the LDL, the bad cholesterol, and reduce the overall cholesterol level. Yet these findings which have been known since the 60's, have never been used effectively in marketing strategy.

Product identity is one of the most important marketing scheme which should be emphasized.

EVALUATE THE PLAN

Finally, like any plan, it needs to be evaluated both during and after the end of the marketing year as to what worked, what did not, and why. In addition, evaluating the plan will assist in identifying areas which need additional work. You may need to expand your alternatives by selecting information on specific marketing strategies, i.e. how much would it cost to add a direct marketing outlet, to sell shelled, cracked, in-shell and selected end products. Who or what would be the target market? Having a marketing plan will help take some of the emotion out of marketing, but it takes discipline to execute the plan.

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Graph 1. U.S. IMPROVED AND NATIVE PECANS 1980-199
Production and Average Price Received (In-shell)

Improved ■ Native ● Improved Price ● Native Price
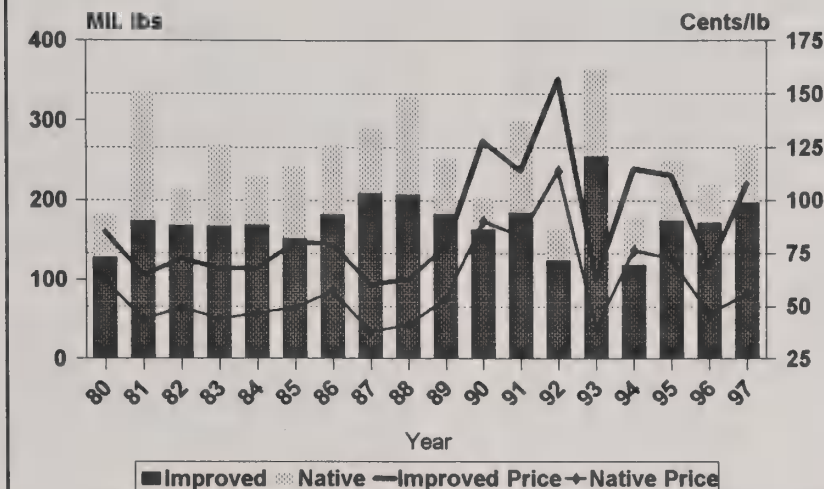
TABLE 1: PECAN ORCHARD COSTS AND RETURNS PER ACRE, 1997			
INCOME			
	Amount	Value/unit	Total value
Pecans (lbs)	900	$1.00	$900.00
EXPENSES			
PRE-HARVEST			
Herbicide (appl)	6.0	$4.42	$26.52
Nitrogen (lbs)	178.0	$0.27	$48.22
Zinc (lbs)	14.0	$0.33	$4.62
Insecticide 1 (Appl)	3.0	$14.06	$42.19
Insecticide 2 (Appl)	2.0	$12.00	$24.00
Fungicide 1 (appl)	2.0	$6.85	$13.70
Fungicide 2 (appl)	1.0	$7.75	$7.75
Irrigation (Ac In)	35.0	$2.89	$101.15
Labor	15.0	$7.65	$114.75
Fuel/Lube/Repairs (passes)	27.0	$1.50	$40.50
Interest Expense	$211.70	9.50%	$20.11
Total Pre-harvest			$443.51
HARVEST			
Fuel/Lube/Repairs (passes)	4.0	$5.50	$22.00
Electricity	1.0	$3.91	$3.91
Cleaning Equip. Repairs	1.0	$36.57	$36.57
Equipment Rental	1.0	$10.90	$10.90
Labor	22.0	$7.65	$168.30
Total Harvest			$241.68
Total Variable Cost			$685.19
break-even Price, Variable Cost		$0.76Per lb of Pecans	
Income Above Variable Costs			$214.81
OVERHEAD			
Administrative overhead	1.0	$16.10	$16.10
Machinery and Equipment	$1,180.00	10.0%	$118.00
Irrigation	$600.00	10.0%	$60.00
Land	1.0	$50.00	$50.00
Perennial Crop	$600.00	5.0%	$30.00
Management Fee\1	$1.00	$100.00	$100.00
Total Overhead			$374.10
Total Costs			$1,059.29
break-even Price, Total Cost		$1.18Per lb of Pecans	
NET PROJECTED RETURNS			($159.29)

1\Management fee for orchards over 500 acres

				Break-Even			Break-Even
	Preharvest	Harvest	Variable	Price	Overhead	Total	Price
Yields	Costs	Costs	Costs	Variable	Costs	Costs	Total Costs
500	$444	$174	$617	$1.23	$374	$ 992	$1.98
600	$444	$191	$634	$1.06	$374	$1,008	$1.68
700	$444	$208	$651	$0.93	$374	$1,025	$1.46
800	$444	$225	$668	$0.84	$374	$1,042	$1.30
900	$444	$242	$685	$0.76	$374	$1,059	$1.18
1000	$444	$259	$702	$0.70	$374	$1,076	$1.08
1100	$444	$276	$719	$0.65	$374	$1,093	$0.99
1200	$444	$292	$736	$0.61	$374	$1,110	$0.93
1300	$444	$309	$753	$0.58	$374	$1,127	$0.87
1400	$444	$326	$770	$0.55	$374	$1,144	$0.82
1500	$444	$343	$787	$0.52	$374	$1,161	$0.77
1600	$444	$360	$804	$0.50	$374	$1,178	$0.74
1700	$444	$377	$821	$0.48	$374	$1,195	$0.70
1800	$444	$394	$838	$0.47	$374	$1,212	$0.67
1900	$444	$411	$854	$0.45	$374	$1,229	$0.65
2000	$444	$428	$871	$0.44	$374	$1,246	$0.62

TABLE 2: BREAK-EVEN PRICE TO RECAPTURE VARIABLE AND TOTAL COSTS OF PECAN PRODUCTION\1

\1 The costs reflected in Table 1

CONSUMER SENSORY EVALUATION OF PECANS

S. Knight[1]

Additional index words: supercritical, SFE, oleic, linoleic.

ABSTRACT

A review of research activities over several years of sensory evaluation of pecans and supercritical fluid extraction (SFE) of pecan oil using supercritical CO_2 has lead to the following observations and conclusions:

- The SFE nut kernels differ in sweetness (more), nutty/oily flavor (less), internal color (whiter), and texture (more chalky or pithy) as compared to non-extracted pecans.
- There is no difference in acceptability between the extracted and non-extracted pecan kernels.
- The SFE adds weeks to shelf life and reduces fat calories by 20 – 30%.
- Packaging at low oxygen levels is not as effective as SFE in extending shelf life.
- SFE causes damage to the internal tissues of the kernels, but this is largely mitigated by slow pressure release.
- The extracted pecan oil is a good, heart healthy product that has many nutritious and gourmet applications.
- The flavor and texture of SFE pecans are similar to non-extracted improved varieties.
- Hexanal level is a good test for the measurement of rancidity in pecans.

Current research efforts with SFE of pecans center on whether other extracting gases yield similar results as to both flavor in the kernels or selectivity of fatty acids in the oil and on development of new uses and markets for pecan oil.

First Sensory
Our first attempt at sensory evaluation of pecans was several years ago working with an Elderhostel group who were experiencing various educational activities at Oklahoma State University. One of those activities was participating as panelists in sensory evaluation. These panelists ranged in age from 55 to 70 and were retired business and professional men and women. None reported being pecan consumers, coming primarily from northern states. They participated in paired comparison testing to determine whether they could tell the difference between Oklahoma native pecans and a large improved variety pecan. They were also asked to describe any differences they detected and rate acceptability. They had no trouble detecting a difference ($p<0.01$), and several reported that the native had a nuttier, oilier taste and the improved variety had a more open, pithy texture. However, the two were rated as being equally acceptable; and, based on plate waste data, found both varieties very acceptable, since the panelists consumed all of both samples.

Hexane Extraction
In cooperation with the Oklahoma Pecan Growers Association, the Nutritional Sciences Department at O. S. U. entered into research to develop a method to reduce the fat level in intact pecan pieces (Waters, 1985). Following procedures similar to those used to extract oil from cottonseed meal, pecan halves were prepared with some left intact and some chopped into different specific particle sizes. Sensory evaluation showed the extracted pecans as having a sweet nutty flavor, with a lighter interior, and an overall rating that was more acceptable than the control pecans. Of the pecans that were chopped, the larger pieces were more acceptable than the ones that were chopped fine, and the finer the chop, the more oil was extracted (15 – 40%). The oil was a nice, pale yellow fluid that was remarkably stable and remained good tasting with a minimum of refinement for many months if kept under refrigeration. This research established that partial fat removal did not diminish acceptability of the kernels and yielded a second product, the pecan oil. The next step would be to determine the effect on shelf life. However, there was a greater residue of hexane remaining in the nuts than proposed FDA rules would allow, so another means of extraction was sought, preferably one that would not present the problem of using explosive compounds. Investigation of supercritical CO_2 as the extracting medium seemed to be a logical choice.

Need for an Objective Test
In related research, Waters (1992) conducted a survey of members of the Oklahoma Restaurant Association to determine if restaurant managers or purchasing agents knew how to determine whether a quantity of pecans was of acceptable quality before taking delivery, and how to maintain quality in the pecans they purchased until use. She found that most of the respondents knew how pecans should be stored, although many did not practice good storage procedures. Additionally, though they were quick to refuse a shipment for obvious carton damage or

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evidence of insect infestation, they did not trust their own judgement to determine whether a pecan was of poor quality due to development of off flavors and rancidity. These findings demonstrated the need for an objective test that would accurately reflect sensory characteristics of pecans.

CO_2 Supercritical Fluid Extraction

CO_2 is environmentally friendly, not explosive, and at the right combination of temperature and pressure becomes a fluid having the oil extracting characteristics of both a liquid and a gas. In interdepartmental research, supported by the State of Oklahoma (OCAST) as well as the departments and colleges involved, a series of three experiments was performed. The first was to determine the parameters for using SFE to extract oil and test the effect of the extraction procedure on subjective and objective characteristics of the pecan kernels. The second was to test the effects of SFE on shelf life of pecans. The third was to test the effects of oxygen levels in packaging on the shelf life of SFE pecans. The departments involved in the research were Horticulture and Landscape Architecture, Biosystems and Agricultural Engineering, and Nutritional Sciences at Oklahoma State University. (Maness, et al, 1995; Maness et al, 1997)

Study I: Effect of SFE on Pecan Flavors

This research had two goals: to determine how flavors and texture changed under different extraction conditions of time and temperature, and to help in setting the parameters for SFE extraction (Chinta, 1998).

Seventeen graduate students enrolled in a research methods course were recruited as panelists. After training in basic flavors, the panelists were trained in pecan flavor and texture attributes. During testing, the panelists rated pecans extracted at 40°C and 80°C for a variety of times.

Significant differences were identified in all attributes measured ($p < 0.05$). The extracted pecans had a whiter interior, sweeter taste, less nutty/oily and roasted flavors, and a texture that was less crisp but more "woody". In spite of detecting these differences, there was no significant difference in acceptability between the extracted and non-extracted kernels.

Through this testing, it was determined that in terms of both fat extraction and effect on the pecans, there was no merit in extracting for more than 20 minutes or at a temperature above 40°C.

Study II: Effect of SFE on Shelf life

This study also had two objectives. One was to determine if SFE would extend shelf life. The other was to see if a chemical test could accurately detect early stage rancidity (Chinta, 1998).

Pecans were extracted (see Table 1) at 40°C for 20 minutes (22% oil removal) and at the same temperature for a longer time - 480 minutes (28% oil removal). The extracted nuts and non-extracted controls were packaged in small bags, each holding about 15 grams of sample. These bags were vacuumed, then backflushed with a generated pure 21%/79% O_2/N_2 atmosphere and held at 25°C for 32 weeks. This followed a 3x10x3 factorial design with three replications that were treated as blocks.

Table 1. CO_2 SFE Extraction conditions

SFE Dionex^R 703 Extractor
Final pressure: 69 Mpa Flow rate: 510 – 680 ml/min

Table 2. Hexanal Determination

Headspace gas GC
    Split injector (ratio 1:50) FID detector
    DB-23 Silica capillary column

Injector temperature: 275°C Detector temperature: 300°C

The small, 40 ml volume of the extraction vessel and the necessity of keeping samples for objective chemical testing presented a challenge to the researchers. Accumulating a large volume of sample material was difficult and the amount to be used for sensory evaluation had to be distributed into packets for evaluation over a 37-week period with three replications. Therefore, only a small amount was available for each sensory testing session. Recognition of this limitation resulted in a select group of four panelists being trained in specific pecan flavor characteristics (see Table 3). The original design was for the experiment to continue for 37 weeks. However, by the end of the 32nd week, one of the treatments was so strong in rancid flavors, further testing was discontinued.

There were initial sensory differences in the 3 oil levels (full fat, 22% reduction, and 28% reduction). The extracted pecans had a lighter (whiter) interior possibly due to the removal of the yellow colored

pecan oil. The non-extracted pecans were the most crisp and the 28% fat reduced were the least crisp. The non-extracted pecans were rated as least chalky, and the 28% fat reduced were rated as most chalky. The non-extracted pecans were oilier than either the 22% or the 28% fat reduced pecans. Non-extracted pecans also had a less toasted flavor than either the 22% or the 28% fat reduced pecans.

Table 3. Pecan flavor characteristics

Color	Testa
	Interior
Texture	Chalky
	Woody
	Crispness
Pecan flavor	Sweet
	Nutty
	Oily
Off flavors	Tannin
	Sour
	Rancid
	Toasted
Overall acceptability	

Table 4. Comparison of Fatty Acid Profiles
(grams / 100 g of oil) (%)

Oil	Sat. Fat	MUFA	PUFA
Pecan	8	62	28 [1]
Peanut	17	45	32 [2]
Olive	14	74	8.4 [3]

[1] 24 as linoleic
[2] all as linoleic
[3] 7.9 as linoleic

There were also flavor changes over time. The perceived oiliness increased in the non-extracted (full fat) pecans during the last three months of the study (after week 18). Rancidity, similar to perceived oiliness, increased in the full fat pecans during the last three months as well. In one of the full fat replications there was, in fact, a significant increase in rancid flavors between weeks 10 and 14. Also, there was a decline in acceptability after week 18.

There were very few changes over time in either of the SFE pecan extraction levels with samples showing neither increasing rancidity nor decreasing acceptability during the entire course of the study.

One of the replications in the 22% reduction level actually increased in acceptability between weeks 10 and 14.

Conclusions were that SFE extraction significantly extended the non-refrigerated shelf life of the pecans. Further, there is no merit in reducing oil beyond 22% in order to extend the shelf life.

Hexanal production was affected by storage time in agreement with Forbus et al. (1980). Hexanal levels ranged from 0 to 16.99 ppm for the full fat (0 extracted) pecans; 0 to 4.44 ppm for the 22% reduced oil pecans; and 0 to 0.56 ppm for the 28% reduced oil pecans during the 32 weeks of storage. Significant levels of hexanal were not detected in any treatments until the 22nd week of storage, when the hexanal in the non-extracted nuts showed an increase, rising above the 6ppm that Hofland et al. (1995) associated with undesirable flavors. At no time did the extracted pecans reach this level, strongly indicating that a low hexanal level could be used as an objective test for presence of rancidity in pecans.

Study III: Effect of Oxygen Concentration on Storage
Delaying oxidative reactions by reducing the oxygen in the storage package appears to be a logical way to preserve pecan quality during non-refrigerated storage. However, a low level of oxygen is necessary to retain normal metabolic activity in the nuts. This level is thought to be in the 2% range (Kays, 1991). Pecans were extracted at 40°C for 20 min. to a oil reduction level of about 22%. This study utilized two extraction levels (0 and 22%), three oxygen levels (2%, 10%, and 21%), over five storage time periods (0, 3, 6, 9, and 12 months). (Chinta, 1998) The pecans were maintained at 25°C and 55% relative humidity in dark storage. Due to the small sample size available for sensory evaluation, the same four panelists used in Study II were utilized for this study and they used score sheets similar to those in Study II. This was a 2x3x5x3 factorial experiment with alpha level of p=0.05, with three replications that were treated as blocks.

There were significant differences in internal color of the pecans. The non-extracted pecans became darker over time, whereas the extracted pecans became lighter. However, these differences were not due to oxygen level. Rancidity scores rose after 6 months at all oxygen levels, but were highest at the 2% level. Also, rancidity scores rose between 6 and 9 months for both the extracted and non-extracted pecans. Acceptability scores for both treatments dropped over time with the lowest scores tending to be after 9

months, but the rate of decline was slower for the extracted pecans.

For this study, the conclusions were that time had a greater impact on development of rancidity than did oxygen level. For all samples acceptability scores declined over time but the rate of decline was slower for the extracted pecans.

Other Research
Electron microscope studies (using both scanning and transmission microscopy) of the SEF pecans showed that extraction was quite disruptive to the internal tissues, and that greater pressure resulted in greater damage. However, there was less damage in pecans extracted in a commercial SEF unit that in the laboratory sized unit. Apparently the larger extraction vessels produce a more uniform, less damaged product. Further, the internal tissue damage could be largely mitigated by releasing pressure slowly. However, the woody or chalky texture the panelists reported in the extracted pecans was probably a manifestation of the tissue disruption. (Knight, et al, 1998)

In recently completed interdepartmental research, a comparison was made regarding flavor changes over time in peanut varieties with three different oleic/linoleic acid ratios. In that study, Watson (1998) found that all three varieties developed rancid-type off flavors, and that the off flavors in the variety with the highest linoleic acid concentration were those best detected by the GC hexanal test. This supports our conclusion from Study II above, and that it is the breakdown of the linoleic acid in the pecans that was responsible for the rancid flavor reported by the pecan panelists.

About the Extracted Pecan Oil
The pecan oil generated through SFE is a light yellow colored oil similar in appearance to corn oil. It is very high in oleic acid (64%), almost as high in this "heart-healthy" monounsaturated fatty acid as olive oil (see Table 4). However the very pleasant flavor of the pecan oil is much more compatible with many types of food than is olive oil. We are currently preparing a variety of foods, cakes and other baked goods, desserts, salad dressings, and gourmet applications for this oil. Also, functional properties of the oil, such as smoke point, should be determined. Our research has also determined that a doughnut fried in pecan oil "is to die for." Pecan oil is quite stable. Although non-refrigerated storage studies have yet to be done, we do know that it keeps indefinitely refrigerated, even if unrefined.

Current Research
Supercritical CO_2, although environmentally friendly and non-explosive, requires pressures of 10,000 psi or more for extraction. Other hydrocarbon gases, when super critical, are also FDA approved for food uses and require pressures of 200 psi or less. Although they do not have all the advantages that CO_2 enjoys, the lower pressure requirements can make such extraction more economically friendly. Therefore, studies are beginning to determine whether these other SFE gases yield similar results as to both flavor and shelf life extension and whether any of these offer any selectivity of extracted fatty acids.

Nutritional Science researchers who have contributed to the information presented in this review include:
Marilyn Waters
Bhaggi Chinta Emani
Debesu Tideg
Jack Huang
Anu Srireddy
Faye Watson

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MARKETING HEALTH ATTRIBUTES OF PECANS

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Additional index words: HDL/LDL ratios, monounsaturated fatty acid, producer check-off programs, tocopherols

ABSTRACT

Dietary monounsaturated safflower oil h[1]as been shown to lower low density lipoprotein (LDL) cholesterol and increase high density lipoprotein (HDL) cholesterol relative to either dietary or polyunsaturated safflower oil or a high carbohydrate diet. The proposed research is designed to determine the influence of dietary monounsaturated pecan oil on human LDL and HDL cholesterol levels compared to those previously investigated safflower oils. Blood samples will be taken at the beginning and after each diet period. Blood lipid analyses will include total cholesterol, total triglycerides, and HDL and LDL cholesterol. If high monounsaturated/polyunsaturated ratios in pecan oil prove that pecans reduce LDL while maintaining high levels of HDL in blood plasma, the struggling pecan industry would have a highly legitimate promotion fact that could revitalize the industry. The industry needs a strong health food promotion because of the USDA Food Guide Pyramid which does not distinguish between pecans and red meat. Hopefully one such study will begin at Scott and White Clinic in Temple, Texas in the fall of 1998. The Texas growers have 70% of the necessary funds needed for this project. The National Pecan Shellers and Processors Association is already sponsoring a pecan dietary study. Pecans have a real advantage in that they are high in oleic acid and γ-tocopherols. Oleic acid increases the HDL/LDL ratio thus reducing the risk of heart attacks and has the higher amount of γ-tocopherols, which is the superior antioxidant. By contrast, almonds are high in oleic acid and low in γ-tocopherols and walnuts are high in γ-tocopherols but low in oleic acid.

INTRODUCTION

Coronary heart disease (CHD) accounts for more deaths in the United States than any other disease. High cholesterol is one of the main contributing risk factors for CHD.

Atherosclerosis is a process in which fatty substances, especially cholesterol and triglycerides (ingested fats) are deposited on the walls of medium-sized and large arteries (Lehinger, 1982; Tortora and Evans, 1986). Cholesterol in the blood is transported in combination with specific aggregates of lipids and proteins called lipoproteins. Cholesterol carried in low density lipoproteins (LDL) is a significant risk factor for CHD.

Cholesterol transported in high-density lipoprotein (HDL) is inversely related to incidence of CHD (Grundy et al., 1982). The objective of dietary control of lipid disorders is to lower the LDL cholesterol and raise the HDL cholesterol. This may be achieved by a food plan low in saturated fat and cholesterol. Saturated fats have been shown to increase LDL cholesterol levels while polyunsaturated fat tends to lower LDL cholesterol and monounsaturated fats raise HDL cholesterol (Food Engineering, 1986). The typical American diet contains about 40% of the total calories as fat, of which 15-17% are saturated fats (Grundy et al., 1982).

The definitive research done comparing the effects of consumption of polyunsaturated versus monounsaturated fats on LDL and HDL cholesterol was conducted by Grundy (1985). In this study, patients consumed diets in which fats composed 40% of the total calories. The patients were divided into 3 groups; 1) saturated fat diet, 2) monounsaturated fat diet, and 3) polyunsaturated fat diet. These fats came from palm oil, high-oleic safflower oil, and high-linoleic safflower oil. Blood samples were taken the third and fourth week. Results indicated that both the polyunsaturated and monounsaturated fat diets had equal effects on lowering plasma LDL. However, the polyunsaturated fat diet lowered plasma HDL more frequently than did the monounsaturated diet.

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In 1986, Grundy compared diets containing monounsaturated acids and those containing high carbohydrates and low fat. The high monounsaturated fat diet contained 40% fat and 43% carbohydrates, and the low fat diet contained 20% fat and 63% carbohydrates. Both diets lowered total plasma cholesterol. The monounsaturated diet lowered LDL by 21% as compared to low fat diet which lowered LDL by 15%. The low fat diet also raised the plasma level of triglycerides and lowered HDL, while the monounsaturated diet had no effect on either of these. Grundy stated that the monounsaturated diet might be as effective as a diet low in fats and high in carbohydrates (Friedewald et al., 1972).

Pecan kernels contain 65 to 70% oil. Approximately 73% of fresh pecan oil consists of monounsaturated (oleic) and 17% polyunsaturated (linoleic) fatty acids.. By contrast, walnut oil contains about 18% oleic, 61% linoleic and 12% linolenic) fatty acid and coconut oil contains 92% saturated, 1% polyunsaturated, and 6% monounsaturated fatty acid (Table 1).

Table 1. Fatty acid % composition of various oils (Sistrunk, 1997).

Oil	16:0^z	18:0^y	18:1^x	18:2^v	18:3^u
Pecan	8	1.0	73	17	0.4
Walnut	8	0.7	18	61	12.0
Coconut^t	7.2	1.5	5.6	1.3	0.0

^{z}Palmitic ^{y}Stearic ^{x}Oleic ^{v}Linoleic
^{u}Linolenic

^{t}Coconut oil contains 84.4% 8:0 to 14:0 fatty acid

Because of the fatty acid distribution in walnuts and pecans, they would be expected to favorably influence when included in substantial amounts in the diet. Sabaté et al. (1993) demonstrated that a diet in which 20% of the fat was derived from walnuts lowered total cholesterol by 12.4%, LDL cholesterol by 16.3% and HDL cholesterol by 4.9%. Almonds have also been shown to have a favorable effect on lipid profiles compared to coconut (Abbey, 1994). Pecans would be expected to lower the total cholesterol and LDL cholesterol and not significantly change the HDL cholesterol based on their content of polyunsaturated and monounsaturated fat. Indeed this was the case in a study by Morgan and

Clayshulte (1997). They found that pecan consumption significantly lowered total cholesterol and LDL-cholesterol in both hyperlipidemic and normolipidemic subjects. Pecan consumption lowered total cholesterol an average of 5% in hyperlipidemic subjects and 4.5% in normolipidemic subjects at 4 weeks into the study. Pecan comsumption lowered LDL-cholesterol by 10% in both hyperlipidemic and normolipidemic subjects at 4 weeks into the study. Pecan consumption did not raise nor lower the HDL-cholesterol (Morgan and Clayshulte, 1997) which is in contrast to the effect of walnuts (Sabaté et al., 1993).

The medical profession and dietitians are familiar with the walnut study by Sabaté et al. (1993), but not the Morgan and Clayshulte (1997) pecan study which had the same quality research, but the former was published in the New England Journal of Medicine and the latter in the Western Pecan Proceedings. Steps are underway to study high profile human plasma lipid and lipoprotein response to a diet high in oleic acid derived from pecans (Storey et al., 1998; Zedan, 1998). The primary differences between these studies and those conducted by Morgan and Clayshulte (1997) is that they will be conducted by professional medical staffs who will be able to publish in national medical journals that will gain the attention of the food editors and dietitians on a national level.

The fatty acid composition of pecans is very similar to olive oil, a fat increasingly popular for its healthful characteristics. Pecans also contribute fiber, proteins, γ tocopherols and phytochemicals such as flavenoids that reduce free oxygen radicals left over from metabolic processes in the human body. The pecan industry must take advantage of the health aspects of their product if they expect to survive as an industry.

Piziak and Storey (1997) have proposed a $50,000 study at Scott and White Clinic in Temple, Texas that would go a long way toward proving to the public that pecans would help prevent heart disease if they were incorporated into their diets. Twenty-four men and 24 women with blood cholesterol levels over 200 mg/dl will be recruited from the Scott and White Lipid Clinic. Diets will be calculated by a registered dietitian with natural foods to provide 20% of the calories as nuts, and total fat content of 30-35% of the total diet. Pecan and coconut test fats will be incorporated into the diets as

unmodified fresh pecans, and coconut commonly found in market channels for eight-week periods. Total fat content will be monitored. Fatty acid profiles will be measured by gas chromatographic procedures for each group of foods.

EXPERIMENTAL PROTOCOL

At baseline, the subjects will complete a seven-day food record. Each subject will be instructed on recording dietary intake and following experimental diets. With the use of the baseline diet record and energy intake, diet plans that incorporate the experimental fats will be developed. Throughout the study, subjects will be followed by the dietitian, nurse coordinator and the principal investigators. The nuts will be distributed by the nurse coordinator and the patients randomized to follow one of three crossover patterns. Each subject will follow each of the three eight-week test diet periods. Thus the study will be a single blind (investigators, and dietitian will not know which phase the subject is in), randomized and prospective.

Blood (5 ml) will be taken from each subject at baseline, and at the end of each test diet phase for cardiac risk profiles and serum fatty acid analysis. All blood samples will be taken following a fast of at least 12 hours. Body weights will be measured during the visit when blood is sampled.

TECHNOLOGY TRANSFER

If diet studies featuring high oleic/linoleic ratios of pecan oil were to prove that pecan oil reduces LDL while maintaining HDL levels in blood plasma, then the pecan industry would have a highly legitimate promotion fact that could revitalize the industry. Many pecan growers, accumulators, and shellers are near bankruptcy. The few orchards that are being sold are going for a fraction of their value. Pecans are native to Texas, Oklahoma, Louisiana, Mississippi, and parts of Mexico so they have been a part of the diet of those who have lived here even before recorded history. Cabeza deVaca noted in 1532 that native pecans were a traditional part of the diet of the native Americans who preceded European exploration and settlement of the southwest and northern Mexico.

If Grundy's results (1986; Grundy et al., 1982) with safflower oil can be repeated with pecan oil, the pecan industry will have the documentation needed to secure a reasonable price for an annual 300

million pound crop of pecans. LDL in human blood plasma can be reduced for millions of people who choose pecans as a better diet alternative than saturated or polyunsaturated fats. The general public has become very health conscious and would react positively to a well documented promotion program on the advantages of monounsaturated fatty acid reduction of LDL in the blood plasma of people who include pecans in their diets. If this research proposal could have been funded in 1989 when it was first proposed there is an excellent possibility that the USDA would not have placed pecans and red meat together on the same place in the food triangle.

INSTITUTIONAL COMMITMENT AND SOURCES OF ADDITIONAL SUPPORT.

Attempts were made to get this proposal funded in 1989 by a special grant from the State of Texas. Growers and shellers were asked to support this research that would have proven that the fat in pecans is good for the human body and should not be classified the same as red meat. Unfortunately not enough people believed in the value of this research in 1989 so we have no way to counter claims that pecans are just another fat to be avoided by the health-conscious public. Everyone must work together to make sure that this project and other like it go forward to save the pecan industry.

Texas A&M University at College Station and at Temple (Scott & White Hospital and Clinic) have the personnel ready and willing to work on this project as soon as it is funded.

THE PECAN INDUSTRY MUST ARISE TO THE CHALLENGE OR FACE DESTRUCTION

Before we can promote anything, we must conduct a vigorous research and development program to gain the hard data necessary for a successful promotion program. We know that oleic acid will increase the HDL/LDL ratio and thus lower the risk of heart disease. However, the oleic acid that has given good results has come from olives and safflower. A successful promotion campaign for pecans must be based on pecans, not olives.

Research takes money. The Texas Pecan Growers Association has raised half of the $50,000 needed to fund the Scott & White pecan study. We currently have $35,000 pledged to the study and hope to have the rest in time to begin the study with the 1998

crop. Land Grant Universities that have supported pecans in the past are reluctant to do so anymore. The pecan research and extension staffs are becoming smaller. As personnel retires they are being replaced by people with no mission in pecans. Commodity organizations that are able to provide leverage support are receiving attention from the Universities. The Georgia Check-Off program collects about $200,000 per year. The Texas Onion Growers put about $250,000 into research and promotion each year. The California Nut Growers are aware of the need for research funds and have supported their industry R&D for many years.

Texas approved a pecan check-off program in the 1970s with an 83% favorable margin, which provided funds for research that moved the industry to marketing pecans on the point basis. Prior to that, native pecans were marketed at prices set by accumulators that were usually based on the lowest quality to be found in a given year. There was little incentive for growers to improve their quality because all nuts were a uniform price per pound. Tree thinning and pecan weevil research was sponsored. The massive county pecan grading demonstrations benefited from check-off funds. However, the state's referendum law was struck down by the Texas State Supreme Court in a 5 to 4 decision following a suit filed by a grain sorghum producer in the high plains on the basis that the act was unconstitutional based on the idea that it violated the Texas constitution which states that raw agricultural products in Texas cannot be taxed. The commodity boards argued that the provision that allowed the producer to file for a refund proved that the check-off was not a tax. This law differed from the Federal IRS law where the citizen cannot file for a refund. The citizens of Texas approved an amendment in the 1980s that clearly states that commodity referendums are not taxes so that now growers can help themselves through this act.

The Texas Pecan Growers Association expressed a need to reestablish the Texas Pecan Check-Off program at their 1997 Annual Conference in Austin. There was only one descenting vote registered by a show of hands at the end of the discussion. The Board voted in February 1998 to begin the process leading to a vote on whether Texas Pecan Growers wish to take their place along with others in saving their industry. A survey of Texas pecan growers in the spring of 1998 showed that 75% of those voting favored the check-off. Officials of TPGA participated in a Texas Department of Agriculture hearing in Austin on May 13, 1998 and have received permission to proceed with the process leading to a pecan check-off election under the Texas Commodity Referendum Law (Perry, 1996) ending on August 17, 1998. The assessment would be ½ cent per pound of inshell pecans sold.

One very important feature of this referendum that differs from the ill-fated national referendum is that assessment will be paid only by producers having 500 or more pecan trees growing on a minimum of 15 acres. Only producers meeting this minimum will be eligible to vote, which follows the pattern of the successful referendum in Georgia. To pass, the referendum must be approved by two thirds of the producers voting, or by producers representing at least 50% of the volume of pecans produced in Texas in 1997-98.

The assessment is to be collected on a refund-only basis by the first handler of the pecans who will deduct the appropriate amount from the purchase price and remit it to the secretary-treasurer of the commodity producers board. A producer may obtain a refund of the assessment by filing an application with the secretary-treasurer within 60 days after payment. The funds collected may be used to fund marketing, education, research, and disease and insect control projects. The funds will be administered by a nine-member board of pecan producers elected by those voting in the referendum. The referendum is expected to produce about $100,000 annually.

TOCOPHEROLS (ANTI-OXIDANTS): ANOTHER IMPORTANT AREA OF STUDY

Tocopherols are antioxidants, which eliminate cancer causing free radicals from the body. Green (1958) has speculated on the importance and biochemical significance of the concentration and distribution of tocopherol. He pointed out a possible relation between the tocopherol pattern of fat and its unsaturation in less methylated tocols predomination in fats of higher unsaturation. The study conducted by Lamberstein et al. (1962) stated that the oleic acid was the major fat in hazelnuts, almonds, and pecans, while linoleic acid was the major fat in walnut oil. Hazelnuts and almonds contained mainly α-tocopherol, and walnuts mainly γ-tocopherols, in agreement with Green's supposition. Pecans, however showed a completely reversed picture with a high content of oleic acid together with mainly γ-

tocopherols (Lambersten et al., 1962). Pecans have a real advantage in that they are high in oleic acid and γ-tocopherols. Oleic acid increases the HDL/LDL ratio thus reducing the risk of heart attacks and has the higher amount of γ-tocopherols, which is the superior antioxidant. By contrast, almonds are high in oleic acid and low in γ-tocopherols and walnuts are high in γ-tocopherols but low in oleic acid.

In retrospect, all tocopherols contained in nuts are beneficial. Tocopherols occur in pecans, and they provide Vitamin E (Santerre, 1996). The high levels of γ-tocopherols in pecans and walnuts (Table 2) provides an excellent health food advantage for those nuts.

Table 2. Average values for tocopherols in nuts (mg/kg)(Lambersten et al., 1962).

Nut	α	γ	Trace
Almond	150	5	
Hazelnuts	10	~15	ξ
Pecans	~15	170	δ
Walnuts	~15	205	δ

γ-tocopherols were far superior to α-tocopherols in extending shelf life (Cort, 1974). γ-tocopherols were also superior to butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) that has been added to foods in the past for extending shelf life. Both BHA and BHT are now in disfavor with various regulating agencies and food processors may be forced to seek other antioxidants. γ-tocopherols provide a natural alternative (Table 3).

Table 3. Comparative antioxidant activity schoal oven, Thin Layer, 45°C (Cort, 1974). Days to reach meg/Kg PV

Antioxidant	Conc %	Chicken Fat	Pork Fat	Beef Fat
None		8	3	10
BHA	0.02	20	28	36
BHT	0.02	15	18	24
di-α-tocopherol	0.02	28	28	38
di-γ-tocopherol	0.02	53	67	70

Tocopherols are natural antioxidants which function as electron donors, they have their greatest effect in protecting animal fats, cartenoids, and Vitamin A (Cort, 1974). Their function as electron donors make them valuable antioxidants eliminating free radicals from the body, lessening carcinogens in the body.

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Discussion - Agricultural Economics Session I - The 3rd Pecan National Workshop, June 21-23, 1998

Moderator: Scott Landgraf, Nobel Foundation
Recorder: Wojciech J. Florkowski, The University of Georgia

After the presentation made by Dr. J. Pena, the following discussion took place.

Tommy Thompson: What is the reasonable yield?

Jose Pena: I hear that 2,000 lbs per acre is achievable in West Texas; yields typically range from 600 lbs to 700 lbs per acre. There is a wide gap in yields. You can probably expect the average yield to be around 900 lbs. Early varieties are good from the marketing standpoint, but they don't yield high. Growers must have a reason for growing them (the early varieties) because they do not yield as much Wichita and Desirable.

Mike Kilby: In Arizona we harvested about 18 mln lbs in 1997, while about 11 mln lbs in 1998. According to producers, yields reach 2,400 lbs per acre every year; but yields range also from 1,500 to 2,000 lbs Shellers offer the price to growers because shellers market pecans. Do we know what does it cost shellers to market pecans?

JP: The cost to market pecans is included in the shelling costs and is hard to extract. Shelling cost for a large sheller range from about $0.30 to $0.40 per lb, depending on the size, quality, and other factors. The retail pecan price dictates what shellers can pay and is based on supply and demand factors, and the meat yield. If shelled pecan meats sell for $3.50-$4.00 per pound shellers can afford to pay $1.00 to $ 1.10 per pound for in-shell pecans. To pay more shellers have to be paid more. In terms of yields, producers tell me that they achieved higher yields, but if you take production and divide it by operational acres, average yields of improved varieties on an up year approximate the yields that we are talking about.

TT: What is the definition of an early variety? Are such varieties yielding lower?

JP: Early varieties are the varieties harvested early. Growers have records and shared the data. I was shocked that yields were in 800 lbs per acre range or even less for early varieties compared to 1,100 lbs to 1,200 lbs per acre in the same orchard for later maturing varieties.

Steve Sibbett: Increasing production was successful for almond production, increasing production is the gist of your problem. From growers standpoint it makes sense to make money by lowering the production per unit, not by expecting high prices. If you can not lower the per unit production costs you cannot make money, unless your land costs you little, etc. The walnut industry has no checkoff program.

JP: In case of almonds and walnuts a certain percentage goes overseas. In order for pecans to be even with walnuts and almonds (market wise), one-half of pecans must go overseas. But yes, the key to profit is to lower the cost per unit to stay within what the market offers.

SS: Marketing strategy is such that the higher production, the more marketing effort. But if you have a static production as shown for pecans, how can you expect marketing to improve what is happening?

JP: Wide production swings are having an adverse effect on market prices. Production was more stable in the 80's than in the 90's. The industry has reverted to wide production swings, creating high uncertainty for large end users and adversely affecting stability in the market. These wide production swings may be signs

of frustration with market prices. As an industry, reducing these wide production swings would be very advantageous.

MK: Somebody told me it took him seven years to figure the pecan market, and was able to do it and that's why we see the price decline.

JP: I'm not sure what a seven-year market cycle means. The point is that growers cannot control the market. They can only control inputs. As Steve was saying, if you increase production with the same total costs, you decrease per unit costs. Growers should apply the concept of marginality, (i.e., compare the cost of an additional unit of input to the value of the additional output produced by using this input). Compare your sprays to the yield response. For example, a spray of herbicides must be linked to yield not to the presence of weeds themselves. Too much concentration of input in terms of the value of the crop, that's where the problem is today. Too much labor inputs. Irrigation water, for example, appears to be applied too often, 7-8 chemical sprays, when 4-5 may achieve the same yield levels. For example, many growers are using tensiometers to manage irrigation water use, yet studies indicate that by using tensiometers, more water is often applied to achieve the same statical yields, etc. The marginality concept is a measure of the input/output relationship. Gradually increase the use of an input until the cost of that input is equal to the value of the product produced while holding other input use constant.

SS: But all inputs applied in one season have implications for the next year's crop, so be careful.

JP: Yes that is very true but, growers still should try to apply the marginality concept to input level use.

SS: Why production swings then? " I reduce the input use" say the growers.

Bill Goff: What is the future of pecan industry? Are we going to lose a lot of growers?

JP: That is a difficult question to answer. The group could, perhaps, answer it better. Up until the 90's, the market generally cleared cash and some overhead costs. Now, market collapses are getting into equity. Some growers haven't survived. Generally speaking, the survivors are better managers, but there are many problems. Crowding is a major problem. For example, I drove from Texas on highway 285. While I didn't physically inspect the orchards, it appeared that a large proportion of the orchards were overcrowded. Overcrowding consumes inputs, yet overcrowded orchards do not produce to their capacity. With regard to Bill Goff's specific question, it appears unlikely that we will have a mass exodus from pecan production.

Marvin Harris: By selecting 10 growers your have the better than average growers, so you will have higher yields and a higher input use. How to account for yields of others if a 900 lbs per acre is higher than average? Do they need to apply more inputs?

JP: The grower set was picked and in this sense, is biased. The input levels were compared to the sample collected in the early 1990's of 57 growers selected at random. In the current sample, inputs were higher (i.e., 6-7 sprays vs. 5 in the early 90's and over 30 inches of irrigation water vs. 20 inches in the early 90's). We needed growers with good records. I don't think their yields were significantly higher or lower than the randomly selected group of the early 90's.

Randy Sanderlin: Your selective group can be considered better than overall, so the problems may be bigger than we recognize.

JP: No, I don't think so. Records were the selection criteria. My opinion of the costs is that cost may be lower across the industry, especially in terms of how overhead costs are calculated.

Bruce Wood: In Georgia 90 % of farmers have not income from farming and have to subsidize their operations from jobs outside farming.

JP: Yes, the same is true in the pecan industry. Some growers continue to produce pecans because they have other crops and/or forms of income. Pecan production increases utilization of their resources to minimize overall per unit production cots.

Nancy Roe: What shocked us was to hear that a pecan buyer when asked if prices were going to improve, the buyer said no.

JP: During the Western Pecan Grower's conference in March 1998, a speaker from the processor's side suggested that growers need to produce 20% more pecans. The question is: if at the current level of production, prices are not clearing the breakeven level, why does the processor industry say we need to product 20% more pecans. I believe the suggestion has to do with production stability.

BG: What are the production costs in Mexico?

JP: Production costs per unit are very close to production costs in the U.S. While labor costs are a lot lower, almost all other costs are higher. Fuel cost are about the same, yields are comparable to the U.S. Interest rates exceed 30%. Bottom line: yield 600-800 lbs per acre, labor costs less, chemicals and equipment cost 20% more, so basically the production costs per unit of production in Mexico are the same as ours.

Esteban Herrera: Some expect the production in Mexico, especially western Mexico, will increase. The total annual production will reach 100 mln lbs Pecan market follows supply and demand conditions and sometimes we expect too high prices. There is some gray area as the industry weights price on other expectations.   If prices are high, we need the imports from Mexico to meet the demand. At the same time Mexico's consumption is hurt, but if price is low, consumption is up. In future we will have middle range of prices, but not a constant price and this will effect pecan use and consumption.

JP: Forward contracting of pecans was offered, but no takers were found. After the two recent market collapses, the marginal price improvement this past season is a good sign, especially since shellers were forecasting large supplies. Shellers estimated the 1997/1998 crop to be much higher than USDA's estimate and imports to be about 80 million lbs from Mexico, so the total sheller forecasts of supplies were high. Shellers tend to lean on higher numbers. If the marginal improvement, despite the forecast of large supplies, is a function of better demand, maybe there will be some improvement this season. Texas is suffering from a drought and the production is expected at about 35 million lbs, with a small native crop. Total production will be way down and a lower level of carry-in stocks is expected. Prices should improve, but don't expect improvements to the price high of the early 90's.

BW: Developing the market is important, but how we can do it if we have no stable supply and quality product. I don't see it. Do like the almond industry: increase supply and drive some out of business?

JP: We'd like to have steady supply of pecans not the one fluctuating by 50% from one year to another.

This portion of the discussion took place after the two other presentations in the Agricultural Economics Session I. Questions were hold until the last presentation was ended.

Tommy Thompson: How did you remove oil? From pecan meal?

Sue Knight: You could, but we used pieces and halves for extracting oil leaving them intact. You could sell such pieces and halves as reduced fat kernels. Reduced fat pecans taste sweeter and many people buy pecans for chopping and adding them to their dishes. You could also put reduced fat pecans in new products because of low fat and fewer calories enable you to able the product 'light' or 'reduced fat', so pecans can enter a new market.

TT: Will the pecan oil be expensive?

SK: Oil is a different product sold on a different market.

Esteban Herrera: Pecans are often rancid. Does the industry needs to better appeal to customers?

SK: Consumers who ate pecans that taste bad could not buy them again. We reported in the paper on studies regarding the controlled atmosphere packaging. In one study it was stated that pecans in a package are living organisms and, therefore, need oxygen. Lowering oxygen levels should help to maintain self life. We extended shelf life by reducing fat, but you may lower oxygen level to two percent; in the atmosphere it is about 21%.

PECAN FOLIAR SPRAY PROGRAMS, PATTERNS AND MATERIALS IN TEXAS

Marvin K. Harris and D. Allen Dean[1]

Pesticide regulation in the United States began in 1910. Congress passed a major bill in 1947, the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), that has become the core of the octopus of subsequent legislation whose most recent tentacles include the Food Quality Protection Act (FQPA) and the Government Performance Result Act (GPRA). President Nixon established the Environmental Protection Agency (EPA) in 1971 by executive order and Congress modified FIFRA in 1972 resulting in assigning EPA tremendous responsibilities regarding pesticides. These legislative processes reflect public concern regarding pesticides and affect everyone. Food and fiber producers and the industries that serve them will have to adapt to sometimes swift and unexpected changes that occur from this well intended legislation. The most recent example in pecan is the loss of Zolone® that occurred in Aug. 1988 when the company elected not to reregister it because costs were high and the minor crop market it primarily served was small.

New pesticides are under increased scrutiny. Producers need to know the role pesticides are playing in their industry so that response to even swift and unexpected change can be orderly and documented in a timely manner. An inventory of spray programs, use patterns and materials is an initial step in planning for change. This begins to document the benefits from current practices and identifies how change may affect the industry. It also provides a standard against which individual producers can assess their own pesticide programs and attempt to improve them furthur.

Pecan, *carya illinoensis* (Wang.) K. Koch, is an abundant riverine species indigenous to North America from western Texas to southern Illinois in the northeast and Oaxaca, Mexico on the south. The wild tree produces palatable nuts that have been consumed by indigenous people for many centuries and more recently used as an item of commerce. Pecan domestication began when settlers thinned riverine woodlands of competing species leaving relatively pure stands of wild pecans. Vegetative propagation techniques developed in the 19th century allowed planting of prized varieties in orchards, which has moved pecan throughout the southern U.S. from California to South Carolina, into western Mexico, and to foreign lands like Australia, Brazil, Israel, and South Africa, as well as bolstering production within the indigenous range. Pecan is also a popular urban tree and many homeowners utilize or sell their production.

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Texas pecan nut production from vegetatively propagated varieties has increased from next to nothing at the turn of the century to about 40 million lbs/yr. Texas pecan production from wild trees (called natives) has fluctuated greatly from 1-70 million lbs annually since 1919, and currently averages about 30 million lbs/yr. (Texas Dept. of Agric. Statistics) Native pecan tree stands are diminishing due to normal tree aging and death and are either being replaced by vegetatively propagated orchards, or, more likely, alternative crops and land uses. Nevertheless, some 40% of Texas pecan production still relies on trees nature planted.

This diversity of tree production is furthur compounded by the size of the production unit ranging from a single tree to thousands of acres, and rural or urban production location, ranging from the arid west to the humid east in Texas. These factors can affect the kind of spray programs, patterns and materials used on pecan in Texas. The data that follows were gathered from surveys of members of the Texas Pecan Growers Association (TPGA) from 1980-1997. The TPGA was founded in 1921, currently has about 600 members, and represents the largest organized accessible group of pecan growers in Texas.

Pecan is attacked by a wide range of pests throughout the season (Fig.1). Producers were asked to rank pests based on their damage to the crop and their difficulty to control them (Fig. 2). Their damage estimates were consistent with more formal studies (i.e., Ring et al. 1986) and based on these perceptions of pest damage, we expected management actions to be directed at these pests. Producers self designated their programs in one of four categories, IPM, Complete, < 3 Sprays/Yr or No Management in a 1997 survey, and the number of zinc, fungicide and insecticide sprays applied by management category is shown in Figure 3. Major differences in spraying occurs among management categories, by definition, and these have been discussed elsewhere (Harris, et al. 1998). The focus of this paper is to examine when treatments were made and what materials were used.

Zinc sprays are used to reduce nutrient deficiencies from rosette and are most effective when applied to rapidly growing tissue following budbreak. The timing of zinc applications reported by Texas producers occurs early in the season (Figure 4). Zinc sulfate is the predominant type of zinc used, followed by NZN, zinc sulfate + uran, NZS and other brands, and with up to six applications being applied during the season (Figure 5).

Fungicide sprays are used primarily to protect rapidly growing pecan tissue from pecan scab, and later in the season from fall foliage diseases. The number of fungicide sprays varies from region to region, with fewest applications in the arid west (0.6) and the highest in the more humid east (3.8) and south (3.4) regions of Texas (Figure 6). Use frequency among the seven fungicides

varies from 1-9 applications per season with Super-Tin used the most followed by Topsin-M, Benlate, Oribit, Enable, Duter and Cyprex (Fig 7).

Insecticide sprays are used to manage a wide range of arthropods throughout the season; directed primarily at gall makers, leaf tatterers and defoliators prior to pollination, pecan nut casebearer from pollination through midseason, and hickory shuckworm and pecan weevil toward the end of the season. The pecan aphid complex may also be the target of some treatments in some seasons. The highest frequency of treatment is for 1st summer generation pecan nut casebearer, followed by other casebearer treatments and shuckworm/weevil treatments; insecticide sprays per producer vary from 1.8 in the west to 3.5 in the southern region of Texas (Fig. 8). There are thirteen insecticide types used by Texas producers 1-9 times during the season, with Lorsban predominating. Figures 9-11 show application frequency by Texas producers in 1996.

Proper use of a pesticide requires applying the correct material at the correct time. Current recommendations are to apply 3-5 zinc treatments annually in the early season to rapidly growing foliage, and fungicide and insecticide as necessary when economic damage from a target pest would otherwise occur. Texas producers practicing a management program average 4 + zinc treatments, 3 fungicide sprays and 3.2 insecticide sprays (Fig. 3). Spray timing
(Figs 4,6 & 8) appears satisfactory for most producers and the chemicals used (Figs 5,7 & 9-11) appear appropriate and for the most part needed.

What follows is an attempt to determine where improvements could be made in pesticide use on pecan in Texas based on the above information. The value of zinc sprays is greatest when foliar tissues are rapidly growing. Zinc sprays applied after early July add little to maintenance of tree health and would be better targeted earlier in the season. Late season zinc sprays represent 16% of the total zinc sprays (Fig. 4). Furthur reduction appears possible, especially in the southern region of Texas where higher than average treatments are made at this time. Zinc sprays appear to be adequate for IPM and complete program producers but the <3 spray per season and no management producers could apply more zinc in the early season (compare Figures 3 & 4).

Fungicide sprays in early season prevent pecan scab and in late season, fall foliage diseases. The newer fungicides have some systemic activity, which allows the producer to delay a spray decision until infection is virtually certain to occur or perhaps has already occurred. There has been a reduction in fungicide sprays on pecan in Texas from 4.2 per season reported in 1980 to about 3 during the 1991-1996 period, probably reflecting this improved flexibility and efficacy. The availability of scab resistant cultivars, the increased recognition that native trees are less

susceptible to scab, and increased attention to weather conditions conducive to scab, may also affect decisions to spray fungicides less frequently. Typically scab sporulation is highest about the time of the second or prepollination spray, but producers in the north, west and east regions sprayed more fungicide in the first spray than the second (Fig. 6). Also, very late season fungicide sprays at late gel and dough stages of nut development would appear to be of limited value in maintaining tree health. These deviations from a theoretically ideal fungicide program are small and most producers appear to be conducting sound fungicide programs based on these data.

Insecticides may be needed anytime during the growing season (Fig. 1), but realistically speaking, are primarily needed to prevent damage from nut feeders, which occur at the 3rd, 5th, 7th, 8th and 9th spray periods (Fig. 8). Insecticide sprays at budbreak (1st spray) could be needed to prevent damage from infestations of phylloxera, scale, and various leaf tatterers and defoliators. The high incidence of insecticide use in the eastern region of Texas may be justified based on these pests (probably a concern about phylloxera), but programs should be carefully evaluated to ensure a target pest is present in damaging numbers before piggybacking an insecticide into a needed zinc treatment. The first few weeks after budbreak are critical to recruiting, establishing and maintaining natural enemies that will help prevent aphids, mites and leafminers from causing problems later in the season. Unneeded broad spectrum insecticide at this time unnecessarily kills natural enemies. The low incidence of insecticide sprays at prepollination (2nd spray) is consistent with the relatively low threat from arthropod pests typically encountered at this time (Fig. 8). The high incidence of insecticide associated with pecan nut casebearer (sprays 3-5) reflect the high level of concern directed at this pest. The 1996 pecan crop was low in Texas. Producers that decided following pollination that no harvestable crop was present, would not have sprayed for pecan nut casebearer. Producers that decided they did have a harvestable crop would likely have aggressively treated for pecan nut casebearer, recognizing that the crop was short and the threat from casebearer very significant. There were 51 producers that did not spray, 74 that sprayed once and 48 that sprayed twice (of the 173 surveyed) for 1st summer generation pecan nut casebearer, and 29 producers that sprayed three times (twice for 1st summer generation casebearer and once for 2nd summer generation casebearer). The 48 producers that sprayed insecticide twice for first summer generation casebearer and the 29 producers that sprayed twice for 1st and once for 2nd generation pecan nut casebearer may be substituting insecticide prophylaxis instead of properly timing fewer treatments.

The evidence for this comes from examination of how IPM program producers sprayed vs how Complete program producers sprayed, the materials they used, and

the yields they achieved. The IPM producers sprayed fewer times than Complete program producers and concentrated their applications on one spray to the 1st summer generation of casebearer (Fig. 12). There were 9% of the IPM producers and 4% of the Complete producers that used $B.$-t compounds more than once and that fall into the prophylaxis category noted above (the shorter residual of $B.$-t compounds could justify applying more treatments to manage casebearer effectively). This results in a minor readjustment of data in Fig. 12 with 10 IPM producers and 29 of Complete program producers (39 total) spraying twice for 1st summer generation casebearer using a broad spectrum insecticide, and 6 IPM producers and 21 Complete program producers (27 total) spraying all three times for casebearer. If the increased sprays applied by the Complete program producers were truly needed to protect the crop, then their yield should have been higher. In fact, IPM program yield was 96 lbs/acre higher for improved pecans and 39 lbs/acre higher for native pecans compared to Complete program producers indicating additional treatments for casebearer were not more effective in conserving yield. Chemical prophylaxis does, however, reduce the need to properly time treatments and simple elimination of some treatments by prophylactic sprayers is not the solution. Spray reduction must be accompanied by an assessment procedure that ensures proper timing of needed treatments to conserve yield.

There were 122 producers that sprayed for 1st summer generation pecan nut casebearer with 45 applying two applications of a broad spectrum pesticide and 3 using a $B.$-t. product. Past research has shown pecan nut casebearer can be managed with one well timed treatment of a broad spectrum pesticide indicating 45 applications could have been eliminated with proper timing. Since 29% of this group consisted of IPM managers and 71% Complete program managers, adoption of an IPM program by the latter would result in eliminating 18 of the 45 applications deemed unnecessary, resulting in 18% rather than the current 27% of prophylactic application. The point here is that while there is clearly room for improvement, there is already substantial agreement between theory and practice in pecan nut casebearer management. Efforts need to be continued to maintain the progress that has been made as well as recruit additional adoption of IPM.

Insecticide sprays 6-9 (Fig. 8), commencing with water stage and ending in dough stage of nut development,

typically target hickory shuckworm, pecan weevil, the pecan aphid complex, and other pests (Fig. 1). The pattern of insecticide use during this period is consistent with these pests and the relatively low incidence of insecticide use indicates producers may actually be underspraying at this time given the threat these pests sometimes pose to pecan production. Special attention needs to be paid to pecan weevil in the last two sprays of the season in the north, west and central regions of Texas, where it occurs. This insect only damages nuts that could otherwise be harvested and densities of just a few hundred per acre can cause economic damage preventable by spraying carbaryl (Sevin®). These data show that Texas pecan producers have increased needed zinc treatments and reduced fungicide and insecticide sprays by targeting pests and better timing of applications over the past two decades. The development and implementation of these more sophisticated management programs has been aided by research and Extension efforts to serve the needs of producers (Harris 1998). The simplicity and relatively low expense of piggybacking "insurance" chemicals with needed materials has been greatly reduced compared to past practices primarily because producers have been willing to learn how to do it effectively. This has kept expenses lower, but more importantly, has reduced the risk of resistance to pesticides, pest resurgence and pollution so that producers and consumers benefit from a healthier more sustainable environment.

Acknowledgments

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Texas Pecan Pest Overview

	J	F	M	A	M	J	J	A	S	O	N	D

YA ——————— BA ——

LT&D

Insects

Secondary:
- Sc, Ph
- Ca, Sa, Ph, WW
- WC$_1$
- WC$_2$, WW, C$_2$
- (WC$_3$), C$_3$

Primary:
- C$_1$
- S (W)

Plant pathogens: S S S FF

Horticultural: N   ZN ZN ZN

Pecan stage: D   BB   Po   W   DS   SS   D

Month: J F M A M J J A S O N D

Pecan Pest Overview - Legend

Insects

BA	Black aphid
C	Casebearer
Ca	Catocala
LT&D	Leaf tatterers & defoliators
Ph	Phylloxera
S	Shuckworm
Sa	Sawfly
Sc	Scale
WC	Walnut caterpillar
WW	Fall webworm
(W)	Weevil
YA	Yellow aphid

Plant pathogens

FF	Fall foliage diseases
S	Scab

Horticultural

N	Nitrogen
ZN	Zinc

Pecan stage

BB	Budbreak
D	Dormant
DS	Dough stage
Po	Pollination
SS	Shucksplit
W	Water stage

Figure 1. Seasonal phenologies of pecan pests in Texas.
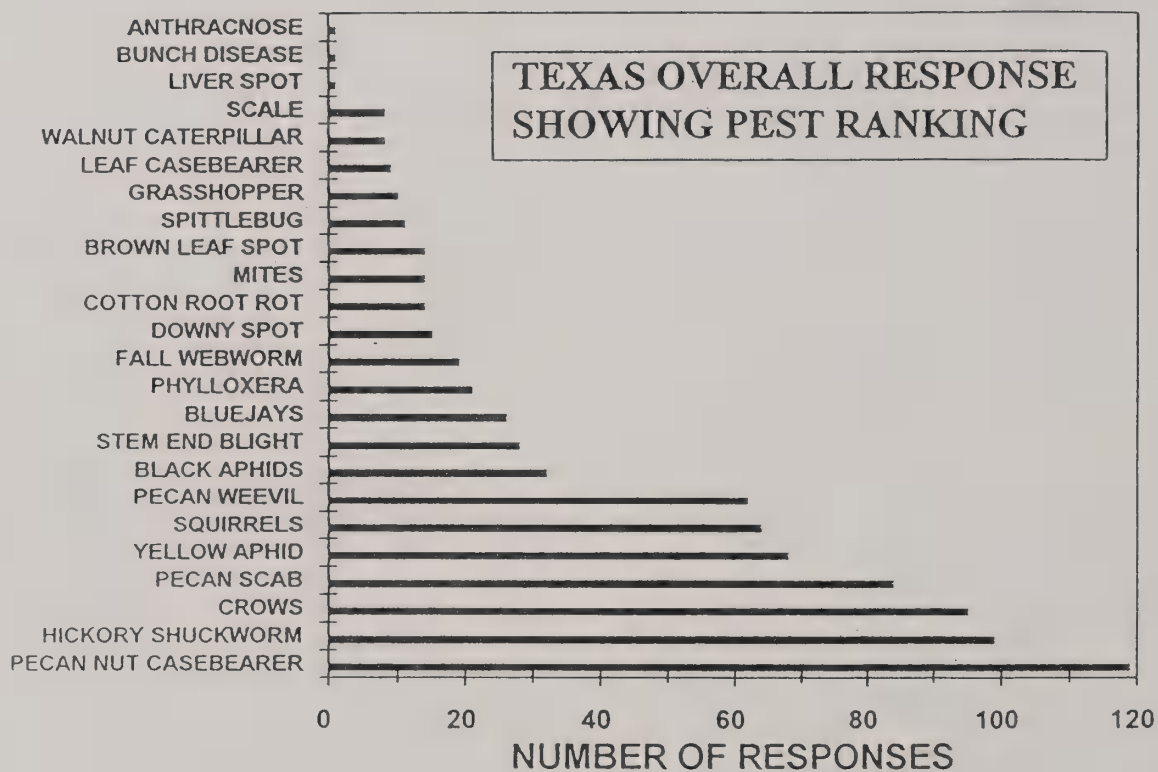
Figure 2. Ranking of pecan pests by 173 Texas producers in 1997.

PECAN MANAGEMENT

TEXAS 1997
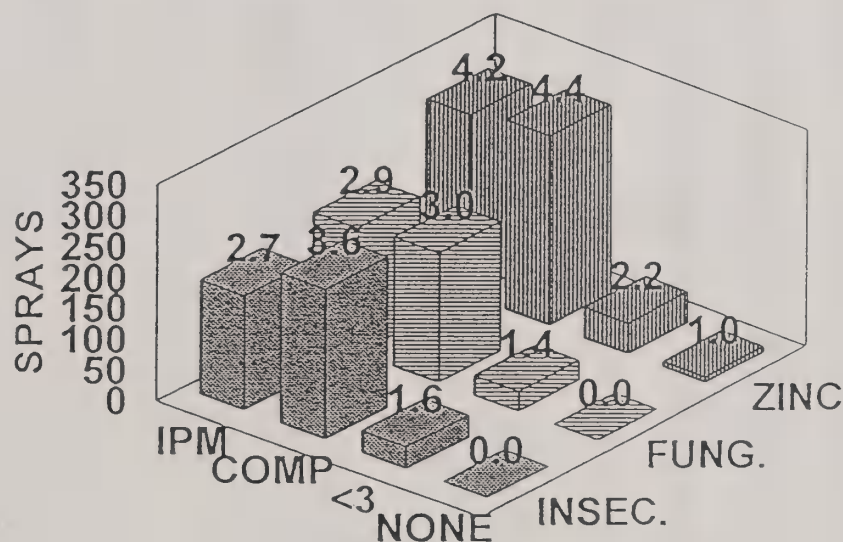
Figure 3. Sprays of zinc, fungicide (fung.) and insecticide (insec.) applied by Texas producers practicing various management approaches from a January, 1997 survey. Numbers in graph denote average sprays per grower applied in the 1996 season.
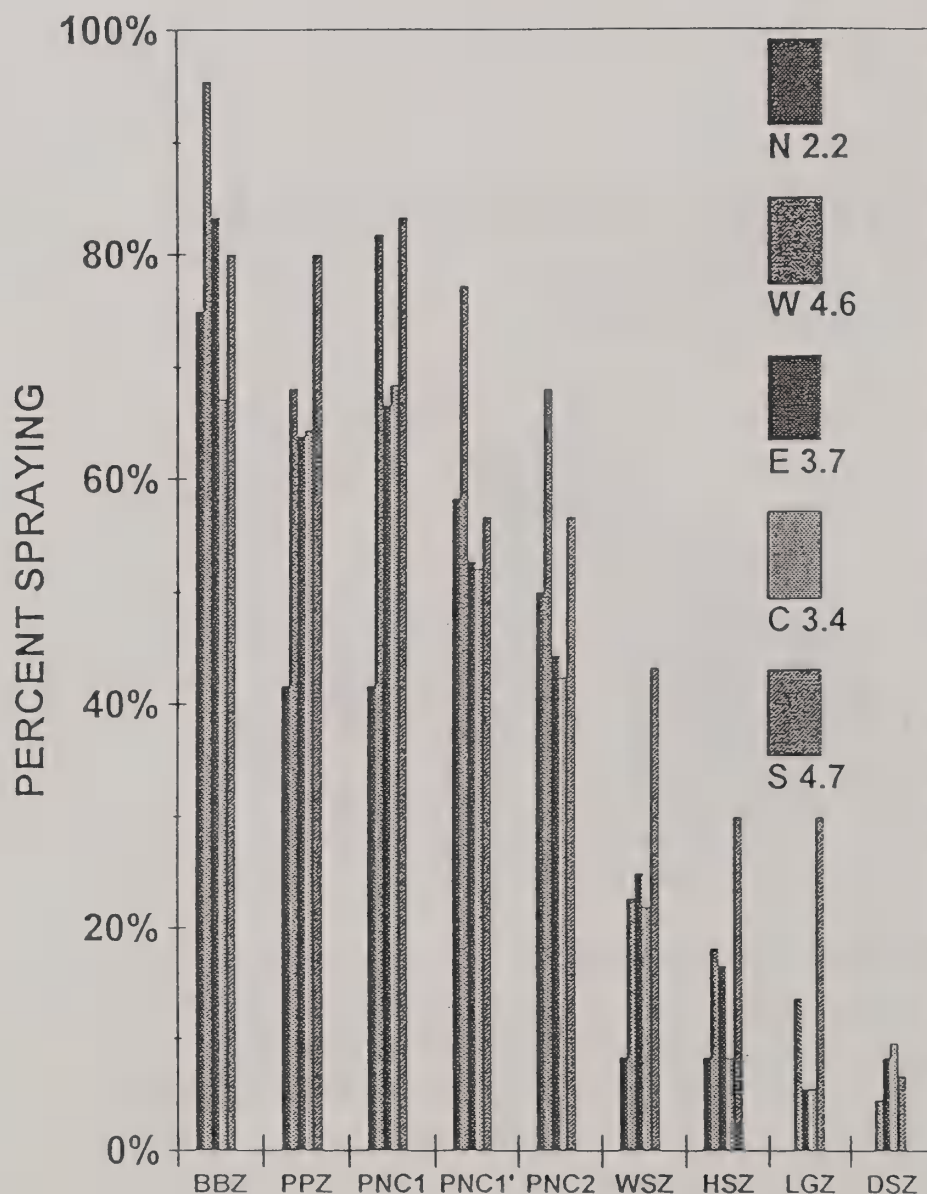
Figure 4. Percent producers in five regions of Texas applying zinc at nine different times during the 1996 season. The X axis legend refers to sprays applied at budbreak, prepollination, pecan nut casebearer 1st summer generation 1st spray, pecan nut casebearer 1st summer generation 2nd spray, pecan nut casebearer 2nd summer generation, water stage, half shell hardening, late gel, and dough stage, respectively, for north (N), west (W), east (E), central (C) and south (S) Texas pecan growers, respectively. Average number of sprays per producer from each region shown in legend.
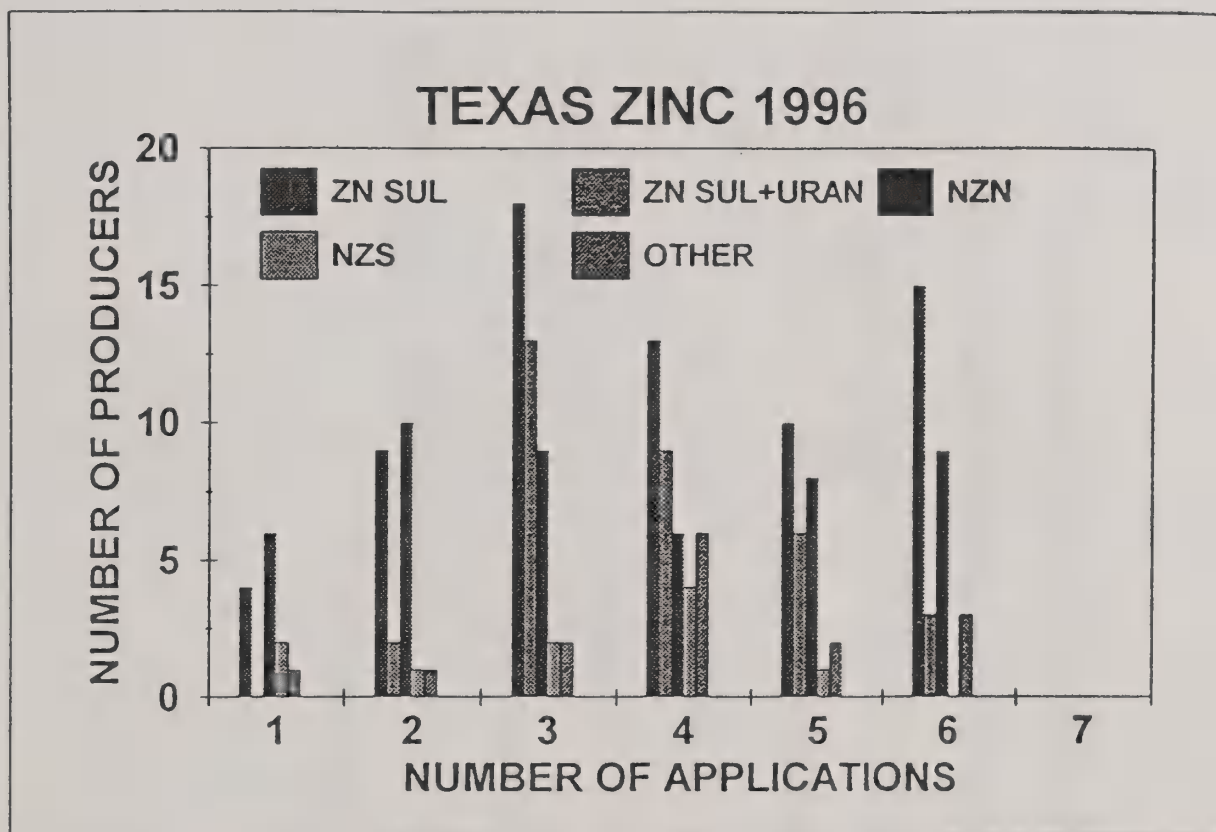
Figure 5. Types and number of applications of zinc used by Texas pecan producers in 1996; zinc sulfate (ZN SUL), zinc sulfate + uran (ZN SUL + Uran) and zinc nitrate (NZN).
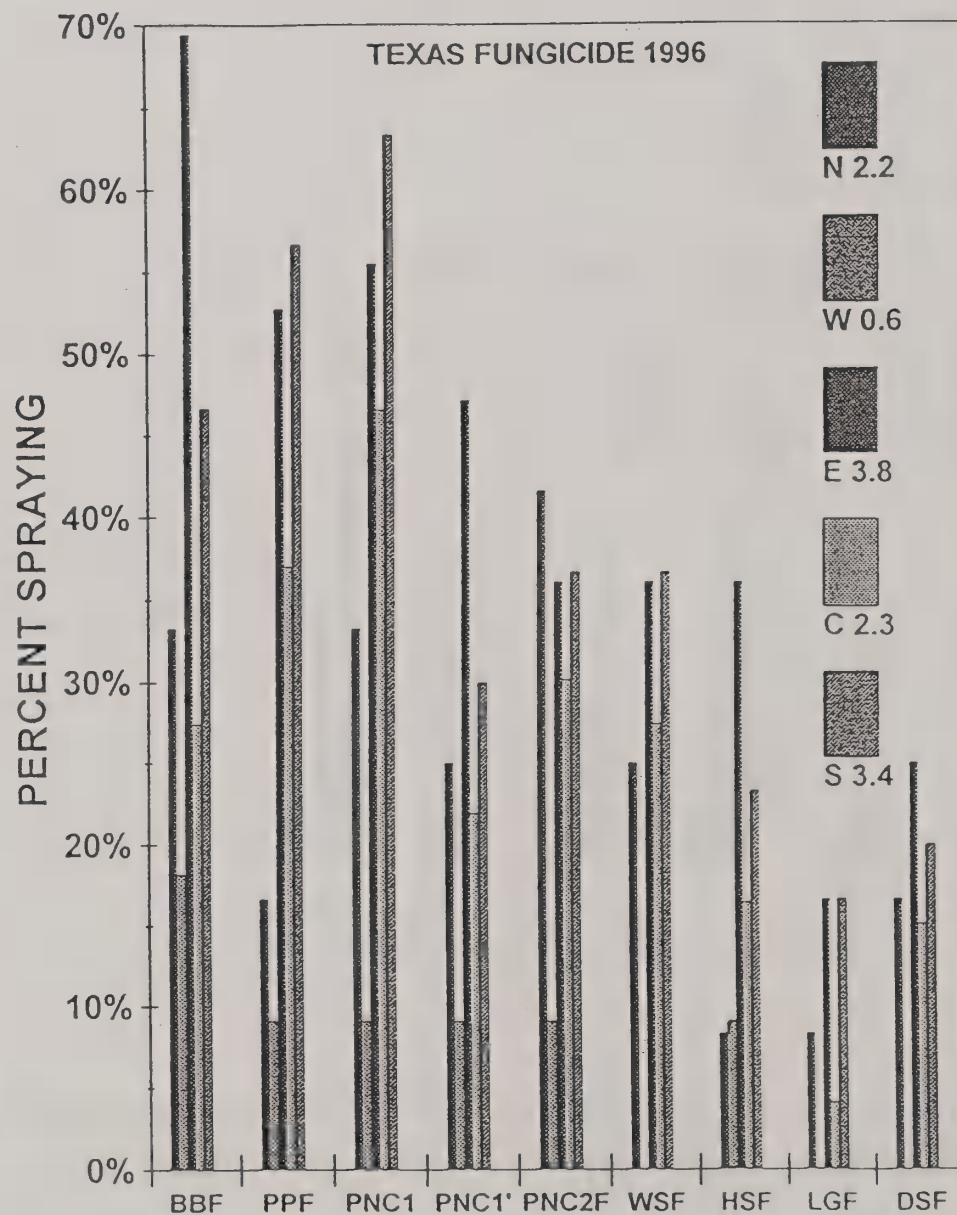
Figure 6. Percent producers in five regions of Texas applying fungicide at nine different times during the 1996 season. The X axis legend refers to sprays applied at budbreak, prepollination, pecan nut casebearer 1st summer generation 1st spray, pecan nut casebearer 1st summer generation 2nd spray, pecan nut casebearer 2nd summer generation, water stage, half shell hardening, late gel, and dough stage, respectively, for north (N), west (W), east (E), central (C) and south (S) Texas pecan growers, respectively. Average number of sprays per producer from each region shown in legend.
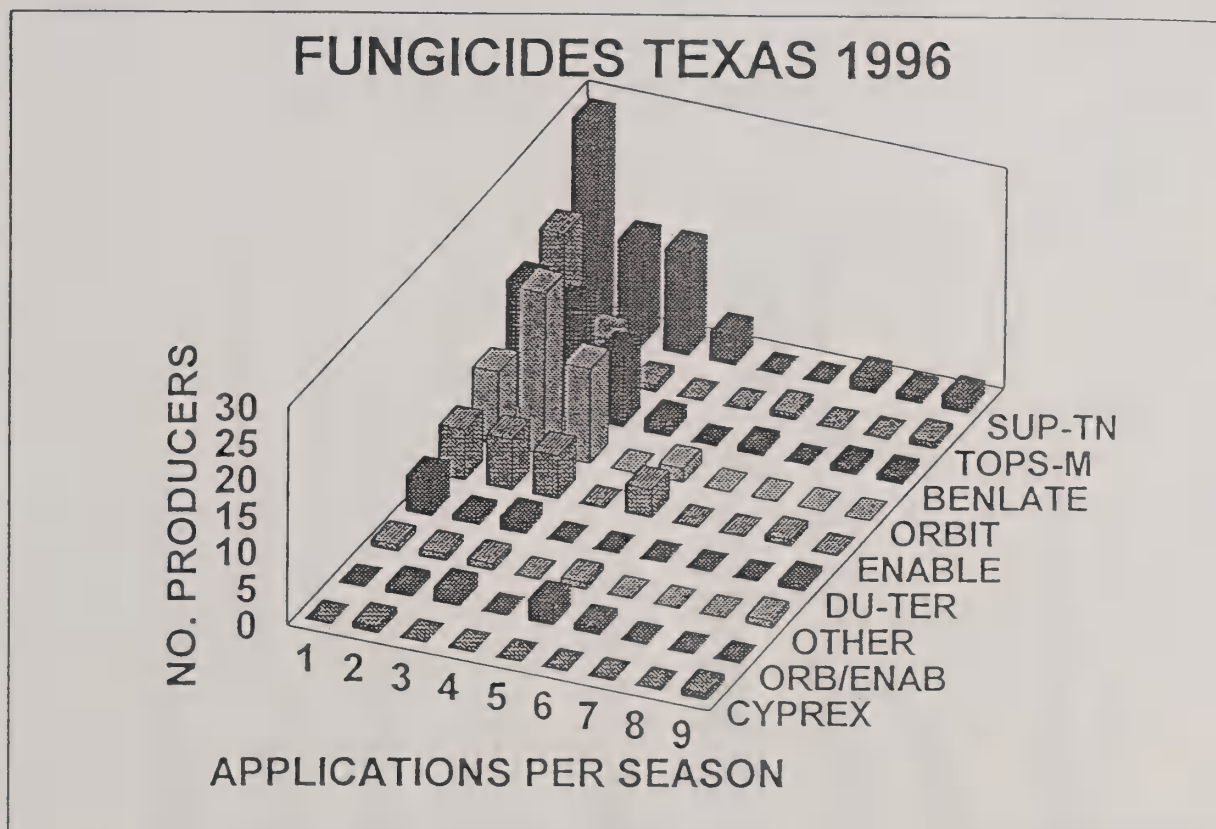
Figure 7. Types and number of applications of fungicides used by Texas pecan producers in 1996. The X axislegend refers to sprays applied at budbreak, prepollination, pecan nut casebearer 1st summer generation 1st spray, pecan nut casebearer 1st summer generation 2nd spray, pecan nut casebearer 2nd summer generation, water stage, half shell hardening, late gel, and dough stage, respectively, for north (N), west (W), east (E), central (C) and south (S) Texas pecan growers, respectively.

TEXAS INSECTICIDE SPRAYS 1996
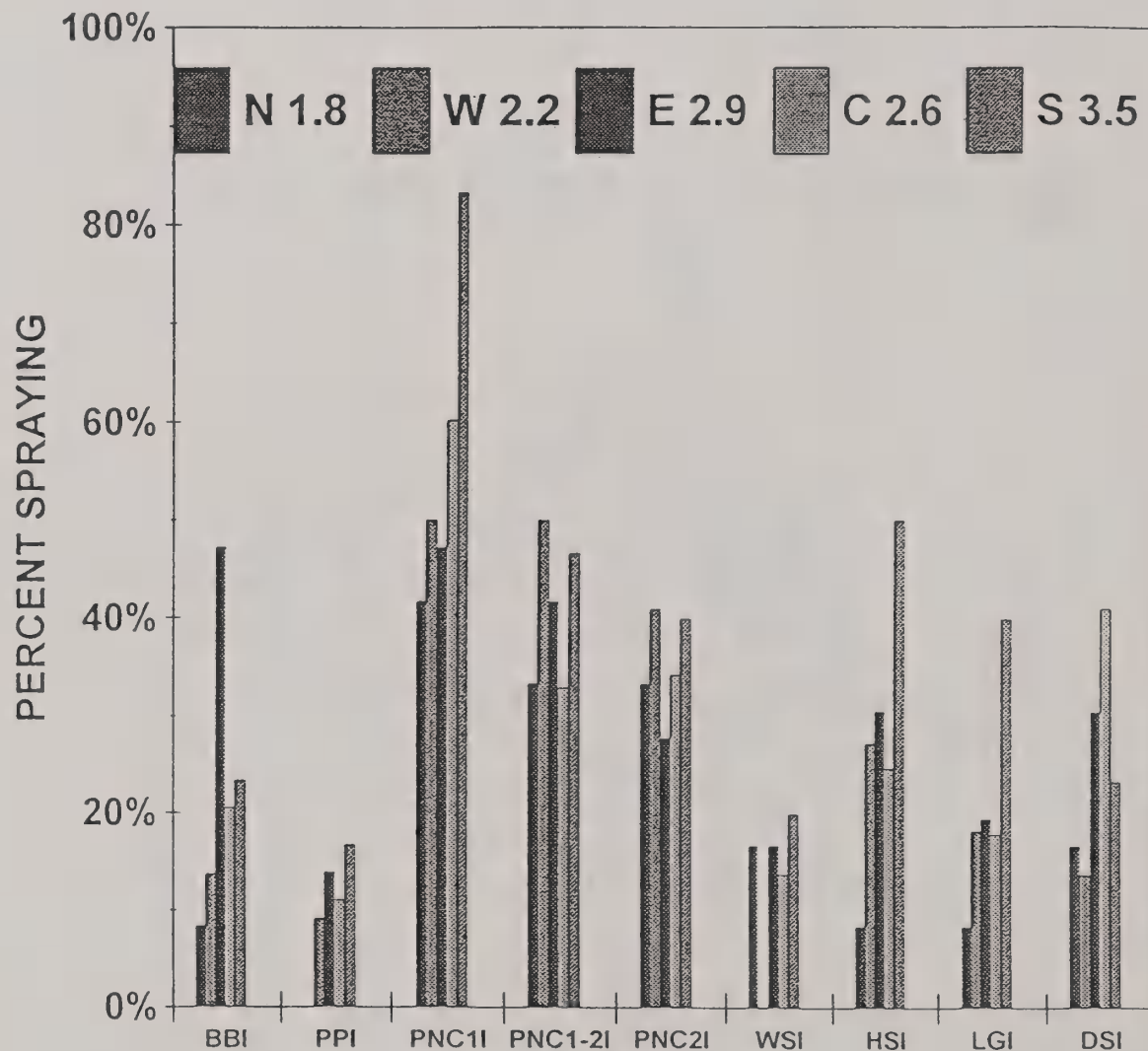
Figure 8. Percent producers in five regions of Texas applying insecticide at nine different times during the 1996 season. The X axis legend refers to sprays applied at budbreak, prepollination, pecan nut casebearer 1st summer generation 1st spray, pecan nut casebearer 1st summer generation 2nd spray, pecan nut casebearer 2nd summer generation, water stage, half shell hardening, late gel, and dough stage, respectively, for north (N), west (W), east (E), central (C) and south (S) Texas pecan growers, respectively. Average number of sprays per producer from each region shown in legend.
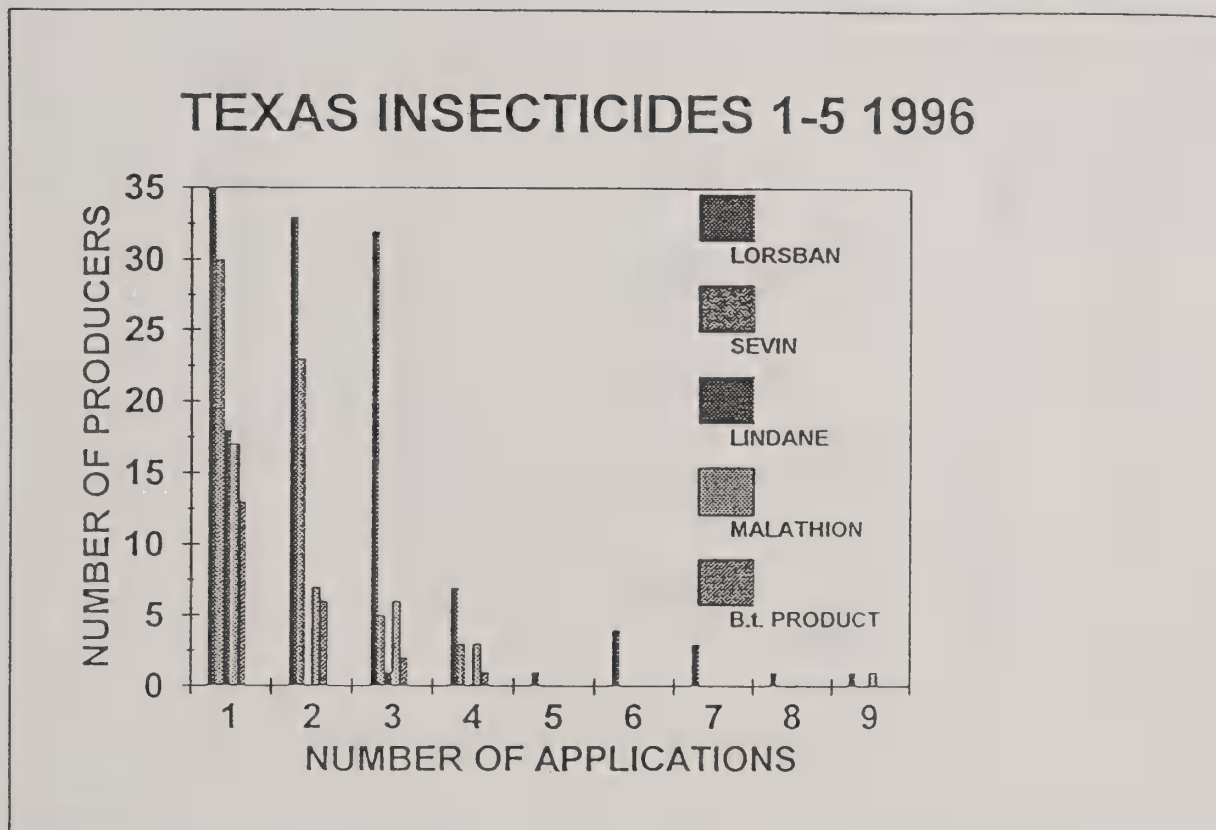
Figure 9. Types and number of applications of the top 5 insecticides used by Texas producers in 1996.
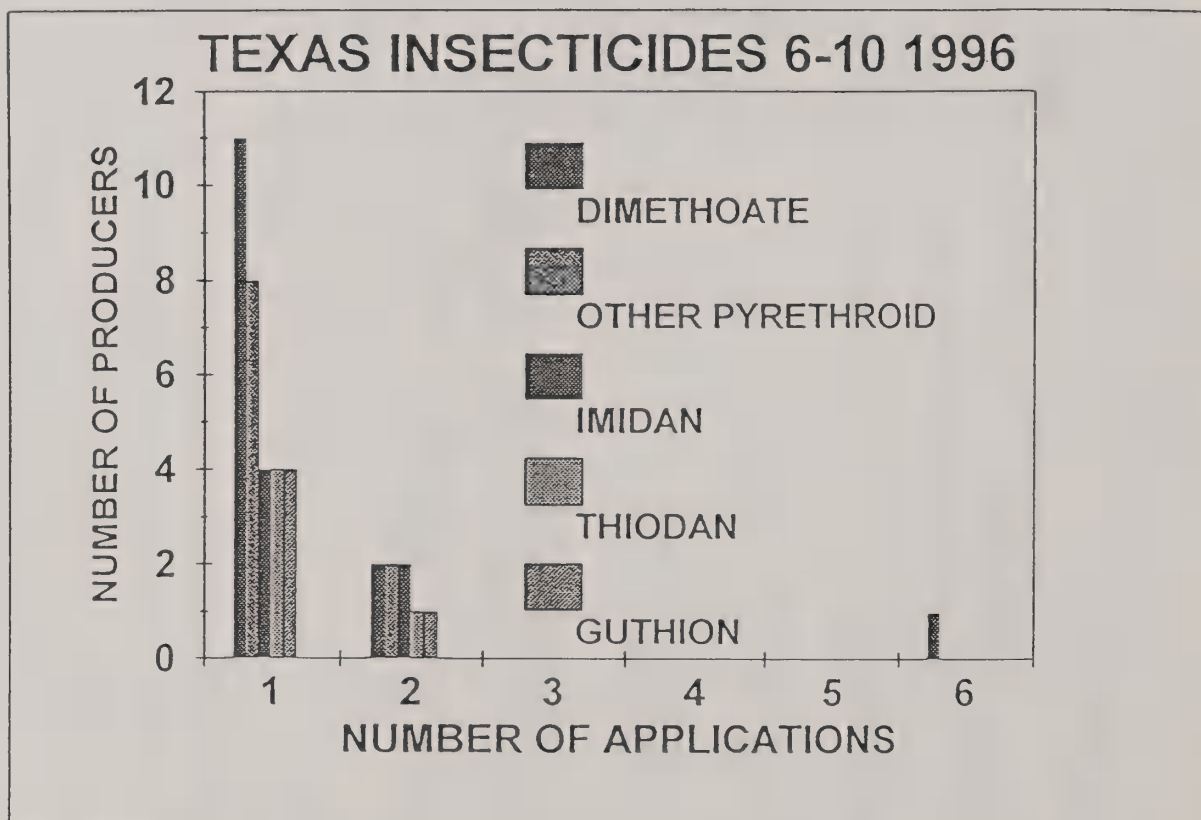
Figure 10. Types and number of applications of insecticides 6-10 used by Texas producers in 1996.
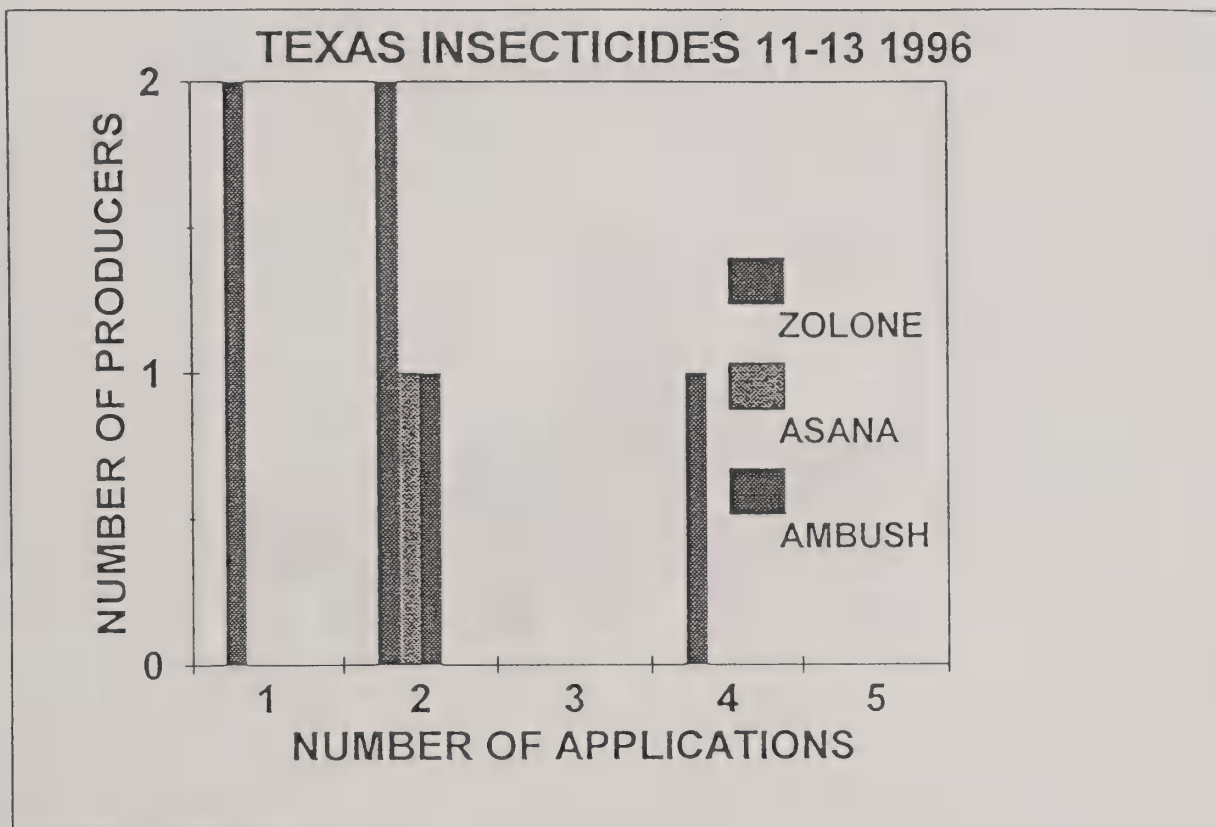
Figure 11. Types and number of applications of insecticides 11-13 used by Texas producers in 1996.
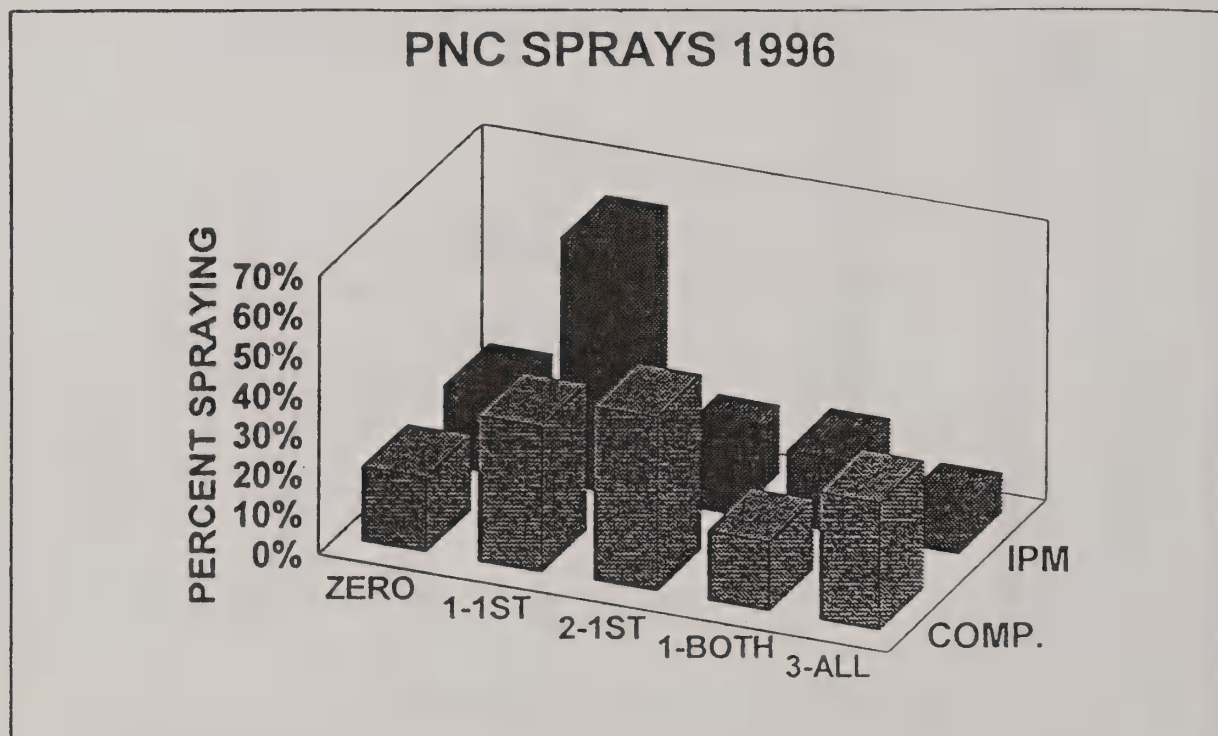
Figure 12. Percent of IPM and Complete program producers spraying for pecan nut casebearer in 1996; spraycategories are no sprays (zero), one spray for 1st summer generation (1-1st), two sprays for 1st summer generation (2-1st), one spray for each generation (1-both) and two sprays for 1st and one for 2nd (3-all).

INSECT AND MITE MONITORING TECHNIQUES

H C Ellis[1]

Additional Index Words. Pecan insects, sampling, orchard surveys, insect traps.

ABSTRACT

Techniques for monitoring pecan insects and mites historically include systematic orchard surveys and trapping. General monitoring procedures and methods commonly used for specific insect and mite pests are discussed.

Pecan growers have always recognized that commercial pecan production requires the control of insect, disease and other pests. Early researchers (Turner, et al., 1918; Leiby, 1925) provided needed information on pecan pests but satisfactory control methods were often unavailable. Following the development of effective, broad-spectrum chemicals and improved delivery technology, a routine spray program keyed to tree phenology, the seasonal distribution of pests and the residual life of available chemicals became the standard pest control method. Usually, growers could apply chemicals at protracted intervals with minimum regard for optimum timing or the precise biology of pests and still achieve satisfactory control. However, several problems developed which made routine, calendar-based sprays less effective and economically impractical, at least from an entomological standpoint. The loss of long-residual, broad-spectrum, efficacious insecticides, increased costs, pest resistance, the destruction of non-target beneficial species followed by pest resurgences and the emergence of secondary pests to problem status placed growers in an ever tightening circle of insect damage and production costs. In an attempt to deal with these problems, pest management (IPM) programs were initiated in several states in the late 1970's. Systematic monitoring of pecan pests was a major part of the IPM programs (Ellis and Brown, 1977; McVay and Ellis, 1979; Ellis et al., 1984). Techniques for monitoring arthropods included regular orchard surveys and insect trapping. Various sampling schemes were proposed, tried in pilot programs and implemented. The rapid development of the "new"

approach used all available information but revealed data gaps (Harris, 1983). Initially, some monitoring techniques were based on best guess estimates of what constituted adequate sampling. Most have changed as new information has become available but many data gaps still exist.

Orchard survey and trapping procedures vary slightly from state to state but usually include similar guidelines.
1. Trees in all segments of each orchard should be sampled. Sampling the entire orchard is important because orchard conditions and pest infestations are seldom uniform. It is usually suggested that ca. 10 percent of the trees be sampled in orchard surveys.
2. Each major cultivar should be sampled. Many pests exhibit varietal preferences. Each orchard should be mapped and cultivars identified.
3. Orchards should be sampled at least once per week. More frequent sampling is advised during periods of peak pest activity.
4. A minimum of five nut-bearing terminals per tree, as high in the trees as possible, should be sampled (most states now suggest 10 terminals per tree). Both the foliage and nut clusters on each terminal should be carefully inspected for the presence of pests or damage. Periodic counts should be made on terminals from shaded, interior portions of trees, primarily for mites and black pecan aphids.
5. Traps should be adequate in number and placed on time to monitor the target pests. Trap placement should be based on history of past infestations when possible.
6. Complete written records should be kept on each orchard. Written records are valuable in monitoring spatial and temporal changes in pest populations and in identifying pest "hot spots" from year to year.

Sampling is usually started at bud break and continued through shuck split. Major foliar pests that are routinely sampled include: the yellow aphid complex, comprising the yellow pecan aphid, *Monelliopsis pecanis* (Bissel), and the blackmargined aphid, *Monellia caryella* (Fitch); the black pecan aphid, *Melanocallis caryaefoliae* (Davis); and the pecan leaf scorch mite, *Eotetranychus hicoriae* (McGregor). Major shoot and nut pests include: pecan spittlebugs, *Clastoptera obtusa* Say and *C. achatina* Say; the pecan nut casebearer, *Acrobasis nuxvorella* (Neunzig); stink bugs (several species) and other kernel feeding hemiptera; the hickory shuckworm, *Cydia caryana* (Fitch); and the pecan weevil, *Curculio caryae* (Horn). Other pests and abnormal conditions are reported as they occur.

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Foliar Pests

By the time that programs stressing the systematic monitoring of pecans began, the misuse of insecticides had elevated aphids from secondary to primary pests. The monitoring of yellow aphid populations provided major impetus to early pecan scouting programs. Yellow aphid populations were assessed by counting the number present (all life forms) on a given number of compound leaves (usually two) per terminal examined. Honeydew accumulation was also rated (0 - 4) from none to heavy with sooty mold. Treatment decisions were made based on these counts and ratings. Action thresholds varied but typically were very conservative. The loss of phosalone and other effective insecticides coupled with the development of aphid resistance to the remaining materials changed the situation. Action thresholds for yellow aphids were raised significantly or eliminated, especially in early season. Growers began to rely more on beneficial insects for aphid suppression and many used habitat manipulation to enhance beneficial populations (Tedders, 1983; Bugg and Dutcher, 1989). Even growers who still tried to control yellow aphids were willing to accept higher aphid levels. Consequently, survey techniques for yellow aphids have been revised and involve more estimation of numbers and less actual counting. This is logical. We currently do not have the technology to determine the difference in impact caused by 50 aphids/compound leaf as opposed to 150 aphids/leaf. One new survey technique was proposed by Tedders and Ellis (1996). The procedure is based on knowledge of the geometric progression of aphid populations and is outlined in Table 1. The categories in the scheme were developed on the premise that under favorable conditions yellow aphid numbers, beginning with one aphid/compound leaf, increase weekly by a factor of three. The method still requires the sampling of compound leaves as described above but reduces the laborious task of counting large numbers of aphids. The technique also suggests that consideration be given to weather conditions, whether aphid populations are increasing or decreasing and the presence of beneficial species, especially *Harmonia axyridis*. High temperatures (above 95°F) naturally suppress aphid development and heavy rains usually reduce aphid numbers and honeydew accumulation. An increasing aphid population contains few adults, many nymphal forms and the aphids, especially the adults, are large and not easily disturbed. A decreasing population contains many small, nervous adults, prone to jump and fly, and many shed skins are usually apparent. This or similar schemes can speed aphid sampling considerably. The approach fits well with our current knowledge base and management

Table 1. Yellow Aphid Assessment and Management Scheme

Category	Survey Method	No. Aphids/Lf.	Next* Examin.	Action
0	Count	0	21 d	None
1	Count	1	14 d	None
3	Count	2-6	7 d	None
9	Count/ Estimate	7-18	7 d	None
27**	Estimate	19-54	7 d	None
81***	Estimate	55-162	7 d	None/ Aphicide
243	Estimate	163-486	—	Aphicide/ Ignore

* Examination schedule if insecticides not applied in previous four (4) weeks. If insecticide applied, examine every seven days.

** 27- Decision making category. Prepare to spray if aphid numbers reach category 81.

*** 81- Spray if weather warm and dry, if increasing population is indicated and if beneficial species not obvious.

tools. As more precise information on damage impact and new control methodology become available, additional changes in yellow aphid survey techniques will undoubtedly be necessary. For example, late-season aphids would be far less damaging if methods were available to suppress sooty mold growth on pecan foliage (Tedders and Smith, 1976.)

Survey techniques for the black pecan aphid have also undergone changes. Initially, counts were made of the mean number of black aphids or freshly damaged spots per compound leaf. Subsequent research showed that monitoring of entire terminals provided a better estimate of black aphid damage potential (Dutcher & Kaakeh, 1992). Presently, it is suggested that all the compound leaves on a minimum of five terminals per tree (usually 10) be examined for live black aphids. Cultivars on which black aphids are known to be a perennial problem (Schley, Sumner, Gloria Grande etc.) should be the focal point of surveys. Black aphid surveys should begin by the middle of April. Black aphids are considered to be primarily a late-season pest but, in recent years, fairly heavy populations have developed earlier in the season. The reason for this is not clear. It could be the wide-spread elimination of early-season insecticide sprays, a loss of effectiveness of current chemicals or some other change in the pecan ecosystem. Early-season black aphids do less damage than those occurring in late season but occasionally require control. Action thresholds have been altered to

reflect these changes. In Georgia, and in some other states, black aphids are now treated when more than one live aphid, especially nymph clusters, are found on 25% of the terminals in early season and on 15% of the terminals in late season (after July 1). Black aphids have become more difficult to control with available insecticides and, to avoid heavy damage, it is now necessary to apply controls before geometric population increases occur. There is a great need for effective, selective aphicides for use on pecan.

The pecan leaf scorch mite has a seasonal distribution similar to black aphids and can be monitored in a similar fashion. Populations of both pests often develop first on low limbs in shaded, interior portions of trees. Mites rarely present a problem before mid- to late- June. They are more commonly a problem in late season following the application of insecticides for control of nut pests. Mites are not a serious annual pest in all orchards but tend to occur in the same locations, even on the same trees, year after year. 'Stuart' seems to be a preferred cultivar and normally is one of the first varieties to show mite damage. Mite populations frequently are unevenly distributed. "Hot spots" can often be identified and monitored. The presence of both mites and mite damage should be considered in surveys. Once mites are detected, examination of the 2nd and 3rd leaflet pairs below the apical leaflet of a compound leaf gives an indication of the mite and egg population on the entire compound leaf (Boethel and Schilling, 1979). Treatment decisions for mites are still rather subjective and factors other than just the presence of mites should be considered. In the absence of damage, the status of the mite population, temperatures, and rainfall probabilities should be weighed. The presence of many eggs and immature forms along with adults usually indicates potential for population increase. If few eggs and immatures are observed and there are many shed skins, the population is probably going to decrease. Heavy rainfall normally reduces mite populations. Mite reproduction ceases at temperatures below 65°F or above 95°F. They reproduce fastest at temperatures between 80°F and 95°F (Jackson, 1980). If summer temperatures are above 95°F for a prolonged period, significant population increases and damage are unlikely to occur. If conditions are favorable and mites and eggs are found, damage is likely to occur within a matter of days. Once damage is found, and if favorable conditions still exist, a miticide application is usually needed within five days to prevent the damage from spreading. If only a few trees are affected, spot treatments are often possible. If mite damage is widespread across the orchard (on 25% of the terminals), the whole orchard should be treated.

Nut Pests

The pecan nut casebearer is usually the first major nut pest of the season. Overwintering larvae emerge when tree growth begins in the spring and feed at the base of buds and in new shoot growth. First generation moths emerge in April - May, depending on temperature, and lay eggs on the small nuts. First generation larvae cause the most serious damage by feeding on the nuts soon after pollination. Insecticide applications are normally targeted at first generation larvae before they enter the nut. Numerous methods have been devised to predict when damaging populations will occur. These include monitoring pupation, adult emergence, egg laying, egg hatch, and nut entry (Bilsing, 1926, 1927; Ring, 1981). Blacklight traps (BLTS) were used to monitor moth emergence (Boethel, et al., 1979; Calcote, 1983). Unfortunately, BLTS were expensive, messy, troublesome to hang and operate and were seldom used by growers. Currently, BLTS are not commercially available and their use is confined largely to pecan scientists. Since the synthesis and release of the pecan nut casebearer sex pheromone, pheromone traps have become the preferred, most effective way to monitor adult emergence (Millar et al., 1996; Harris et al., 1997). Precise determination of the onset of adult activity coupled with knowledge of pecan nut casebearer development (Ring and Harris, 1983; Ring et al., 1983; Sparks, 1995) now allows more accurate prediction of the critical period for nut casebearer control. Pheromone traps should be placed in orchards no later than April 15. It is normally suggested that at least five traps be placed per orchard. In orchards larger than 500 acres, at least one trap per 100 acres is suggested. Once moths are caught, egg laying, egg hatch and nut entry can be reliably estimated (Ree, 1998). Trap catches cannot be used to determine the extent of pecan nut casebearer damage or the need to apply an insecticide but they can shorten the period when intensive nut inspection is required to make treatment decisions. Surveys for eggs and nut entry should begin within 7 to 10 days after first moth catch and be continued, at least twice weekly but preferably every other day, until two weeks after peak moth emergence or until a treatment is applied. Surveys made as previously described are usually adequate. Depending on the state, treatments are suggested when from one to three percent of terminals are infested with eggs or larvae. Once damage to the first nut is detected, treatments must be applied within two days to avoid additional nut loss. The sequential sampling scheme proposed by Ring, et al. (1989), can often speed sampling but has an action threshold lower than those used by most states.

The hickory shuckworm begins attacking pecans in early June and continues until harvest. Early shuckworm generations build up in hickories and phylloxera galls. Examination of phylloxera galls for the presence of shuckworm larvae can give an indication of potential shuckworm problems. Prior to shell hardening, shuckworms cause nut drop. After shell hardening they tunnel in shucks, causing stick tights, discoloration of the shell, reduced quality and delayed maturity. The traditional approach to shuckworm control was an insecticide application in mid June followed by three additional applications, at two week intervals, beginning in early August. When monitoring programs were initiated, BLTS were used to monitor moth activity. BLTS were even considered as a suppression method for hickory shuckworm (Tedders, et al., 1972). However, as previously stated, BLTS were never widely accepted and were little used by producers. The development of a hickory shuckworm pheromone (Smith, 1985) and the ensuing availability of pheromone traps improved adult monitoring capabilities in some areas but the traps proved less than satisfactory as a monitoring tool in the Southeast (McVay, et al., 1995). They provide limited information on shuckworm activity early and late in the season but are not adequate in June and July when shuckworm is causing nut drop. BLTS are still the best tool for monitoring adults. BLTS are maintained by pecan workers in several states and information on moth activity is provided in grower advisories. In the southeast, mid-season hickory shuckworm problems must be monitored by close inspection of nuts in orchard surveys. Orchard surveys should include checks for shuckworm damaged nuts beginning in early June. The white, powdery residue indicative of shuckworm egg laying is usually readily visible on nuts. Nut drop counts should also be made to determine the percentage of drop caused by shuckworm. Some growers collect shuckworm infested dropped nuts and hold them in a screen-covered container at field temperatures to determine the onset of the next moth flight. The technique has met with fair success if enough nuts are collected (Tedders, W. L., personal communication). The levels of mid season shuckworm injury and shuckworm caused nut drop that can be sustained without economic loss remains to be determined. In Georgia, it is suggested that mid-season shuckworms be treated if four percent of the nuts examined on terminals have shuckworm damage or if 10% of dropped nuts have damage. This guideline is not based on data. It was produced simply to give growers some direction. It is loosely based on damage levels normally tolerated for other nut pests. It is never good to base treatment decisions on damage but it is necessary due to the lack of accurate, site specific

techniques for monitoring adults. Most growers are willing to tolerate some shuckworm damage in June and July. They are reluctant to apply insecticides at this time and risk stimulating an aphid outbreak. Monitoring of late-season shuckworm infestations can also involve inspection of nuts. However, no guidelines have been developed for late season infestations. It is generally assumed that shuck infestation causes less economic loss than direct nut loss but data are not available which clearly define losses to late-season shuckworms. In the absence of guidance, most growers apply late-season insecticides for hickory shuckworm based on when advisories tell them shuckworms are active and on recent past history of infestation. This is not a desirable situation. Practical, effective, site specific monitoring techniques for hickory shuckworm are sorely needed. Most growers who have pecan weevil infestations in their orchards rarely make insecticide applications for hickory shuckworm. They rely on weevil sprays for shuckworm control. Normally, shuckworms are adequately controlled by weevil sprays.

The pecan weevil damages pecans by adult and larval feeding. Prior to shell hardening, adult feeding causes nut drop. Once shells harden and nuts reach the gel stage, eggs are laid within the nuts and developing larvae destroy the nut kernels. Weevil controls are aimed at the adults. Various methods have been used to monitor the levels and emergence of adult weevils. These include nut inspection, limb-jarring, assorted tree-trunk traps and bands, ground cover tarps, knock-down sprays, pheromone traps, cone cage traps and malaise traps in tree crotches (Neel and Sheppard, 1976; Dutcher, et al., 1986). Each of the methods has advantages and disadvantages. Combinations of methods are sometimes used. Two recently developed monitoring methods (traps) have proven very effective in detecting pecan weevil adults and are currently preferred for weevil monitoring. The pyramid trap developed at the USDA Southeastern Fruit and Tree Nut Research Laboratory in Byron, Georgia (Tedders and Wood, 1995) and the circle trap, developed in Oklahoma (Mulder, et al., 1997) are now widely used. The pyramid trap is placed on the ground about 10 feet from the tree trunk. Circle traps are attached to the tree trunk. The pyramid trap is more extensively used, probably because they are commercially available, easier to place and because it is sometimes difficult to properly attach the circle trap to large pecan trees with low scaffold limbs. Both traps serve to adequately indicate weevil presence and relative abundance. Weevil traps should be established in orchards no later than July 15. One trap per tree is sufficient. At least 10 to 15 traps should be placed per orchard and

indicator trees, known to have a weevil infestation, should be used when possible. It is desirable to have 10 to 15 traps for each 100 acres. Weevil distribution within orchards is not random. It is best, at least with the pyramid trap, to place traps under several trees in close proximity in known weevil areas. Whitewashing or wrapping the trunks of sample trees in white plastic enhances trap catches with the pyramid traps. Traps should be checked and emptied every two to three days. Traditionally, pecan weevil controls have been applied when adult emergence is detected and nuts have reached the dough or gel stage of development. Controls are commonly continued every seven to 10 days until emergence stops. Unfortunately, many growers lack confidence in their ability to determine if emergence has stopped or has just slowed. Many unnecessary weevil treatments are applied each year. These traps appear to offer a degree of sensitivity in detecting weevils that may allow suspension of sprays when weevil emergence temporarily declines, such as during a prolonged dry spell. Improved sensitivity in weevil monitoring may give growers the confidence to omit unneeded weevil applications and thereby reduce the severe aphid and mite problems that commonly follow repeated weevil sprays. The development of an effective weevil pheromone could further improve the precision of weevil sampling and would be of great value. Pheromone work is underway (Hedin, et al., 1996; Mulder, et al., 1997). Action thresholds have been suggested for the pyramid trap. Once nuts are susceptible to oviposition, control measures should begin when an average of 0.3 weevil/trap/day is caught (some states use 0.4 weevils/trap/ day). If trap catches stop, sprays can be suspended until emergence resumes. Traps should be maintained and checked until shuck split. Early in the weevil emergence period, monitoring with traps should be supplemented by orchard surveys to check for weevil feeding damage and for nut drop caused by weevil feeding. Occasionally, when weevil populations are very high, an early spray is necessary to prevent economic damage from adult feeding. The greatest need in weevil management is for effective controls which do not disrupt the pecan ecosystem and cause outbreaks of secondary pests.

Stink bugs and other kernel feeding hemipterans can damage pecans throughout the season. As with other direct nut pests, those feeding on the nuts before shell hardening cause nut drop. After shell hardening their feeding causes black, bitter spots on nut kernels. Late-season damage is usually more serious due to bug influx into pecans as weeds and agronomic host crops, such as corn, soybeans, peas, and cotton, begin to decline. Alternate host crops, especially legumes,

should not be planted adjacent to pecans. However, research is underway into using small plots of leguminous crops, beans or peas, as trap crops (Smith and Hall, 1996). Trap cropping looks promising as a sampling tool and as a method of reducing bug damage. Additional information is needed on the most effective plants, planting dates, plot sizes, and plot placement. Traps based on a modification of the pyramidal trap (Tedders and Wood, 1995) have been developed for monitoring hemipterans (Mizell and Tedders, 1995). Their use has been coupled with a pheromone for *Euschistus spp.* stink bugs (Mizell, et al., 1997; Yonce and Mizell, 1997). This work to holds promise for improved stink bug monitoring capabilities. The traps have proven very effective in catching *Euschistus spp.* and may reflect the relative abundance of bugs in general. They have not been as successful in catching the southern green stink bug *Nezara viridula* (L.), another damaging bug pest. More work is needed to determine the effective range of the traps, if trapped species truly represent resident bug populations and how trap catches correlate to damage potential. Presently, there are no efficient and reliable sampling methods for stink bugs. Nut bearing terminals are monitored for the presence of bugs but, due to low numbers and bug mobility, a larger than normal sample size is usually needed to assure detection. Border trees near alternate host crops are usually surveyed. Treatment guidelines suggest that sprays be applied if one stink bug is found per 40 terminals. On a practical basis, most growers spray stink bugs if they have alternate crops nearby, if bugs are relatively easy to find in their trees and if they have a past history of damage. As with hickory shuckworm, growers with weevil infestations usually rely on weevil sprays to control stink bugs.

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MANAGING PECAN APHIDS

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Pecan aphids often develop to high population levels in commercial pecan orchards when natural controls fail or the aphids develop insecticide resistance. The grower has three control options. First, preventive application the systemic insecticides, aldicarb or imidochloprid in the early summer protects the tree for most of the growing season. Second, application of contact insecticides to the foliage when aphid populations reach an 'action level' of abundance prevents outbreaks of aphids and the trees accumulate damage from low population levels during the entire season. Third, enhancement of aphidophaga with intercrops, ant control and selective insecticides reduces overall aphid abundance during most seasons but aphid outbreaks are common.

Research on pecan insect control is conducted to design control tactics that prevent insecticide resistance development in aphids and aphid resurgence as well control nut pests. In recent years, more specific insecticides and more accurate and precise monitoring techniques have given growers the tools to Specific aphidicides are becoming available for use against pecan aphids.

APHID BIOLOGY

The aphid species have similar life cycles: overwintering as eggs on the pecan stem; nymphs hatch out at budbreak and begin feeding on the emerging foliage developing into winged adults that reproduce by parthenogenesis; inhabit pecan all season long with no alternate host plant outside of the Juglandaceae; prefer to feed on the phloem from the underside of the leaf; and, the highest populations occur in the Fall before the appearance of sexual forms. Each species has unique field biology. Yellow pecan aphids colonize the pecan foliage as the foliage emerges and first appear as high populations in the Spring on the top three leaflets of the compound leaf before the leaflets are fully expanded. These aphids move to the rest of the compound leaf. Feeding on the abaxial phloem, yellow pecan aphid causes damage at the junction of the coarse and lateral

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veins. Populations peak in May and decline rapidly as summer temperatures increase with a second peak of activity in the Fall. Black pecan aphids appear in the spring as newly hatch nymphs feeding on the buds and expanding leaves. The first adults appear on the upper and lower surface of the compound leaf and quickly disperse through out the tree. Black pecan aphids are more damaging to 'Schley' than to 'Stuart' and early season damage does not usually cause defoliation whereas late season damage leads to rapid defoliation as early as late August. Black pecan aphids feed on the tertiary and quaternary veins of the leaflet. Blackmargined aphid populations appear in the Spring on as nymphs and adults across the surface of the underside of the pecan leaf in lower numbers than yellow pecan aphids and they gradually increase over the summer. Blackmargined aphids feed on the main vein of the leaflet. Important publications on pecan aphid biology (Tedders 1978, Flores-Flores 1981, Edelson 1982, Neel et al 1985) outline the biology in more detail.

Pecan aphid seasonal development appears to be regulated mainly by temperature, rainfall, aphidophagous insects, and the condition of the pecan foliage. The spring populations decline with sustained high temperatures. Temperature effects in aphid survival and growth rates (Flores-Flores 1981, Edelson 1982, Reilly & Tedders 1990, Tedders et al 1992, Kaakeh and Dutcher 1993a) indicate that aphids survive extreme temperatures for short periods of time and population growth is possible over a wide range of temperatures. Rainfall can significantly reduce pecan aphid populations to varying degrees depending on the duration and amount of rain (Kaakeh and Dutcher 1993b). Aphidophagous insects are a diverse group in the pecan tree (Dinkins et al 1993,)that regulate populations throughout the growing season (Liao et al 1984).

Population growth rates of pecan aphids are among the fastest in the aphid family. Blackmargined aphid increases faster than yellow pecan aphid which increases faster than black pecan aphid. The fecundity (nymphs produced per female) is same (during early season) or higher (during late season) and prereproduction time (time from birth to first reproduction) is shorter for the black margined aphid than yellow pecan aphid. Black pecan aphid has a longer prereproductive period and lower (during spring and summer) or the same (during the fall) fecundity than yellow pecan aphid (Kaakeh and Dutcher 1992).

APHID CONTROL

Chemical controls of pecan aphids include preventive application of aldicarb, a systemic insecticide, in the spring and summer. Insecticide sprays to the foliage are used to reduce aphid populations during outbreaks to prevent further feeding damage. Application techniques have been in place for the last twenty years though improvements have been made in scouting techniques (Dutcher 1997c) and sprayer technology (cf. Reilly et al in this publication). The main change in aphid control has been the loss of efficacy of insecticides for the foliage sprays (Dutcher 1997d) and the registration of imidochloprid as a preventive soil application and a foliage spray (Dutcher 1995, 1996). Foliage sprays of insecticides affect aphid probing behavior (Hurej and Dutcher 1994a) and reduce the survival of ladybeetles (Hurej and Dutcher 1994b) and lacewings (Hurej and Dutcher 1994c).

The biological control of pecan aphids continues to be a reliance on natural enemies during the growing season. Aphidophaga are most effective where insecticide applications are reduced and predators are released (LaRock and Ellington 1996); intercrops and ant control (Dutcher 1994a. 1995b); and, selective insecticides (Dutcher 1993, 1994b, 1995a). Tolerance of higher populations of aphids reduces the number of insecticide sprays and enhances natural enemies. There appears to be a difference in the damage impact of aphid feeding in the southwestern and southeastern growing regions of pecan with southwestern plantings having neglibible production losses from damage and southeastern orchards having early defoliation followed by significant yield reductions.

Control of aphids is also possible with the application of pottassium nitrate and/or a surfactant to the foliage (Wood et al 1995, 1997) this is less expensive than using a chemical insecticide and would not, in my view, have as serious impact on beneficial insects.

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PECAN WEEVIL MANAGEMENT CONSIDERATIONS

Marvin Harris[1]

The keys to pecan weevil management are: 1) to determine if pecan weevil density is sufficient to cause economic damage; 2) if it is, treatment must be timed properly to maximize efficacy, and 3), monitoring must be continued following the first treatment to ensure retreatments, if needed, are also applied in time to prevent newly emerging pecan weevil adults from causing damage.

DETERMINING ACTION LEVELS FOR PECAN WEEVIL

The pecan weevil has primarily a 2 yr life cycle, with a few requiring 3 yrs (Harp and Van Cleave 1976). This means the adults that will attack the 1998 pecan crop come primarily from larvae that fed on the pecan crop in 1996 (and perhaps a few in 1995). A good rule of thumb has been developed to anticipate the damage potential of pecan weevil to the current crop by using field infestation data gathered from the same orchard two and three yrs previously (Harris et al 1981). We know that unmanaged pecan weevil given adequate food will increase about 4.81 (±2.6) times from one generation to the next generation two yrs later, and about 0.48 (± 0.4) times for the three yr portion of the life cycle (Harris et al 1981). This means that a 10% pecan weevil infestation of a 500 lb/acre crop two and three years previously will be capable of increasing about 5 times in the current year so that about 50% of a 500 lb/acre crop could be damaged. Of course, crop loads can vary from year to year and pecan weevil infestations also vary. This is accounted for in the following formula: Expected Damage Capacity of Pecan Weevil in Current Year = (% infestation 2 yrs ago x lbs/acre yield 2 yrs ago x 5) + (% infestation 3 yrs ago x lbs/acre yield 3 yrs ago x 0.5). Note that pecan weevil damage in 1997 is not important to what happens in 1998. Weevil damage in 1997 will provide most weevils in 1999 and some in 2000 to attack those crops.

A simple example for 1998 is suppose 500 lb/acre crops were produced in 1995 and 1996, and each had about 10% infestation from pecan weevil. Larvae from infested nuts emerged in the orchard prior to harvest and entered the soil where they are now adults that will emerge to attack the 1998 crop beginning in late August. Calculation of damage capacity to the 1998 crop is (10% x 500 x 5) + (10% x 500 x 0.5) = 250 + 25 = 275 lbs/acre that pecan weevil can damage in 1998. This damage level is expected whenever you have a crop of 275 lbs/acre or larger in 1998; a shorter crop is expected to be completely infested for all practical purposes. Figure 1 shows expected yield losses in the

current season calculated from various amounts of pecan weevil damage to crops of various sizes two years previously. Generally speaking, pecan weevil in the current year will damage five times as many pecans as were damaged two years previously.

COMPARING RISK FROM PECAN WEEVIL TO MANAGEMENT COSTS

The preceeding method is simple and uses easily obtainable field data to determine the risk from pecan weevil in the current year in lbs/acre of inshell pecan nuts. These data must be converted to $/acre and compared to management costs to determine if control can be economically justified.

Native inshell pecans are smaller and sell for less than improved pecans. Pecan weevil adults however damage an average of 15 nuts/adult regardless of nut size or price so that the damage caused per weevil is a function of nut size and price as shown in Figure 2. Choctaw pecans weighing 40/lb and selling at the modest price of $1.50/lb are damaged at the rate of 56¢/adult weevil. By contrast, small natives weighing 100/lb and selling at the fire sale price of $0.50/lb are damaged at the bargain rate of 7.5¢/adult weevil. Management costs average about $25/acre/treatment and as many as three treatments may be required to control pecan weevil resulting in a total cost for pecan weevil management of $75/acre, regardless of nut size or price.

This means the number of adult pecan weevil needed to justify spraying for them depends on nut size and price. Figure 3 shows the number of weevils per acre needed to cause $75 in damage to pecans varying within the size and price ranges presented in Figure 2. The key point of Figure 3 is that less than 1000 adult weevils per acre are needed to cause economic damage. Under the threshold conditions of Figure 3, treatments may still be undertaken for a number of reasons. Perhaps management can be achieved using just two treatments, or pecan prices may be higher than those shown, or reducing future risk (year 2000) from pecan weevil may be a consideration. This ballpark method allows the producer to consider the risks from pecan weevil and plan a management strategy before the events occur in 1998.

MONITORING PECAN WEEVIL VS. MEASURING DENSITY

Another method to assess risk from pecan weevil is to monitor adult emergence from the soil in the current season using cages or traps of various kinds. This should be a routine tool for every grower expecting to have to spray to protect their crop from pecan weevil because these monitoring aids identify the time when adults are emerging from the soil to enter the pecan canopy and infest pecans there. The drawback to using cages and traps to assess risk or potential damage from pecan weevil is that emergence

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is not complete before treatments to prevent damage must be undertaken and obtaining accurate pecan weevil density estimates requires very intensive trapping (Boethel and Eikenbary 1979, Harris et al 1981).

This becomes clear when one considers the number of pecan weevils/acre that will cause $75 of damage (note this equals maximum expected management costs; see Figure 3). How can you accurately detect a few hundred or even a thousand pecan weevil adults/acre using cages or traps? The short answer is, if you are finding emerging pecan weevils in late August onward you are very very likely to have more than the minimum density to justify treatment and the question is not whether to spray, but when to spray to prevent damage.

But, let us consider this question of density a little more. No ordinary pecan grower I have ever met has used sufficient traps to accurately detect 1,000 or fewer pecan weevils/acre in time to spray. There are 43,560 ft² in an acre. Adult weevils will emerge from soil beneath the pecan canopy and well spaced trees will cover about 50% of that area so weevils emerging from about 22,000 ft² need to be detected. This means a density of 1,000 weevils/acre will be distributed on average 1 weevil for every 22 square feet that will emerge sometime from August to November. The standard cone emergence cage covers about 7 ft² and three are therefore needed to cover about 22 ft² (Harris et al 1980). About 30 such emergence cages are needed to detect 10 weevils at a density of 1,000 weevils/acre over the entire season, and if just 10 adult weevils accumulated in those 30 traps by the end of the season, you should have sprayed. But you can't wait until the end of the season to make that decision. The first spray for pecan weevil in Texas is typically needed when only 10% of adults have emerged by late August. With 30 standard cone emergence traps, chances are about even that 1 weevil would be captured at this time given an economically damaging population of 1,000 weevils/acre. One needs more cages than 30 to accurately assess such a density, perhaps as many as 120 (Boethel and Eikenbary 1979). Accurate detection of just 300 weevils/acre in time to spray effectively would require even more cages.

The trapping effectiveness of cone cages can be increased by using Leggett tops (Neel and Shepard 1976, Anon. 1990) that capture adults emerging beneath the trap and those that land on the outside of the trap and walk up it into the top. The problem with using this capture data to measure density is that the trapping area is unknown. The weevils originating outside the cage have come from some unknown distance away. Similar difficulties exist with burlap trunk traps, tygon tubing, tire traps, open bottomed cages suspended in trees (see Neel and Shepard 1976, Knutson and Ree 1998) and the new pyramidal traps (Tedders and Wood 1994). These latter methods often allow more effective detection of pecan weevil activity, but are less accurate in measuring density for reliable treat/no treat decision making.

My conclusion is that precise detection of pecan weevil density is presently too expensive and time consuming to warrant building, maintaining and monitoring the 120 or more cone cages needed to detect economic threshold numbers of emerging pecan weevils. Traps and cages are best used for deciding when to treat and orchard history combined with current season evaluations should be used to determine if treatment is needed. Generally speaking, if pecan weevils can be detected, economic damage is likely to occur if management action is not undertaken at the right time.

TREATMENT AND RETREATMENT DECISION MAKING FOR PECAN WEEVIL

Pecan weevil adults can emerge from the soil to attack pecans from August to November, as noted above, but typically emerge in greatest numbers from late August to early September in Texas (Figure 4). Females can successfully lay eggs any time after late gel stage of nut development until shuck split. There is a 3-5 day preoviposition period following emergence before the female begins egg laying. Carbaryl typically has a 5-7 day residual activity. A continuously emerging pecan weevil population entering pecan canopies with nuts between late gel and shuck split will require repeated treatments at 8-12 day intervals to prevent damage. The first treatment can be delayed until trees with the earliest maturing nuts enter the late gel stage of development and weevil emergence has begun. Early maturing varieties like Pawnee enter the late gel stage in August, sometimes before any weevils have been detected emerging from the soil. They are very susceptible but safe from attack until weevil emergence begins; then they must be treated within a few days and if weevil emergence continues after 5 days from the treatment date, they must be retreated within 8-12 days from the last treatment date, and this must be continued until emergence ceases. Later maturing varieties like Mahan can accumulate weevils in the canopy until the onset of late gel in late August or early September and then treated to prevent oviposition. Again, if weevil emergence continues after 5 days from the treatment date, retreatment must be made 8-12 days after the initial treatment and this must be continued until emergence ceases. Native trees vary from early to late maturing varieties and typically begin entering gel stage in mid August with a few not doing so until the 3rd week of September. Irregular spacing and distribution of natives usually prevents treating them individually and spraying is usually conducted based on the earliest maturing trees experiencing weevil emergence. These decisions are summarized in Figure 5.

Although the susceptibility period for pecan weevil attack extends from late gel to shuck split, emergence typically occurs in one or two peaks in Texas with the first taking place the last week in August through the first week of September and the second, if a second peak occurs at all, following a soil softening rain or

irrigation that releases the remaining drought-delayed weevils from the soil. The latter can occur as late as November and these late emerging weevils will attack nuts that have not undergone shuck split. This is why monitoring pecan weevil activity in the orchard is essential. Treatments of carbaryl must be applied to prevent susceptible nuts from egg laying by emerging female pecan weevils. Making these decisions when to treat requires monitoring nut development and soil conditions, and detecting weevil emergence before during and after treatment to determine if retreatment is needed (Fig. 5).

CHECKING DROUGHT-DELAY

The first treatment is made when weevils are detected emerging from the soil and nut development is in late gel or dough. Monitoring of soil conditions at this time will help anticipate whether part of the weevil population will be drought delayed. If soil hardness is harder than $60kg/cm^2$, a portion of the population will be delayed in emergence (Schraer et al 1998). This can be crudely measured by taking a 6" section of a ½" dowel rod, embedding it in a handle, and exerting about 130 lbs of pressure on the flat tip of the rod against the soil surface to test soil hardness. If the rod penetrates the soil 5-6" in depth with 130 lbs pressure or less, no drought delay is expected and weevil emergence should occur over a 2-3 week period in a normal manner; if the soil is too hard to allow weevils that can't access soil cracks or root channels to emerge, then they will be delayed until rainfall or irrigation softens the soil surface above their cells to a hardness of $60 \ kg/cm^2$ or less. The moisture required for this softening varies with soil type and preexisting soil conditions (Schraer et al 1998). Several areas within the drip line of representative trees should be checked to determine the likelihood of a drought delay and monitoring traps and cages should be maintained and checked until the danger of delayed emergence is past or harvest has occurred.

RECOMMENDED PROGRAM FOR PECAN WEEVIL

Determine if a harvestable crop worth protecting from pecan weevil is present.

Check the orchard crop and pecan weevil infestation history to determine the risk from pecan weevil. Establish a crop, pecan weevil and soil monitoring system in early August. Monitor for onset of late gel stage in the crop and beginning of pecan weevil emergence at least twice a week. Pyramidal cages (Tedders and Wood 1994) are inexpensive and effective pecan weevil monitoring devices that work best when adjacent trees are whitewashed. These and other devices are discussed by Knutson and Ree (1998). Apply the first treatment of carbaryl when pecan weevils have begun emerging and earliest maturing trees are in late gel (or dough if no weevils were present at late gel). Check soil hardness to determine

likelihood of drought delay. Apply a second treatment 8-12 days after the first if weevils continue to emerge 5 or more days after applying the first treatment. Continue monitoring and treating as needed until harvest. Generally speaking, a maximum of three treatments should be sufficient to protect most pecans in most years when drought delay occurs and two treatments should be sufficient when pecan weevils emerge normally in late August and early September. Take yield and pecan weevil infestation data for use in decision making in future years.

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PECAN WEEVIL YIELD LOSSES
FROM YIELD AND DAMAGE 2 YRS AGO
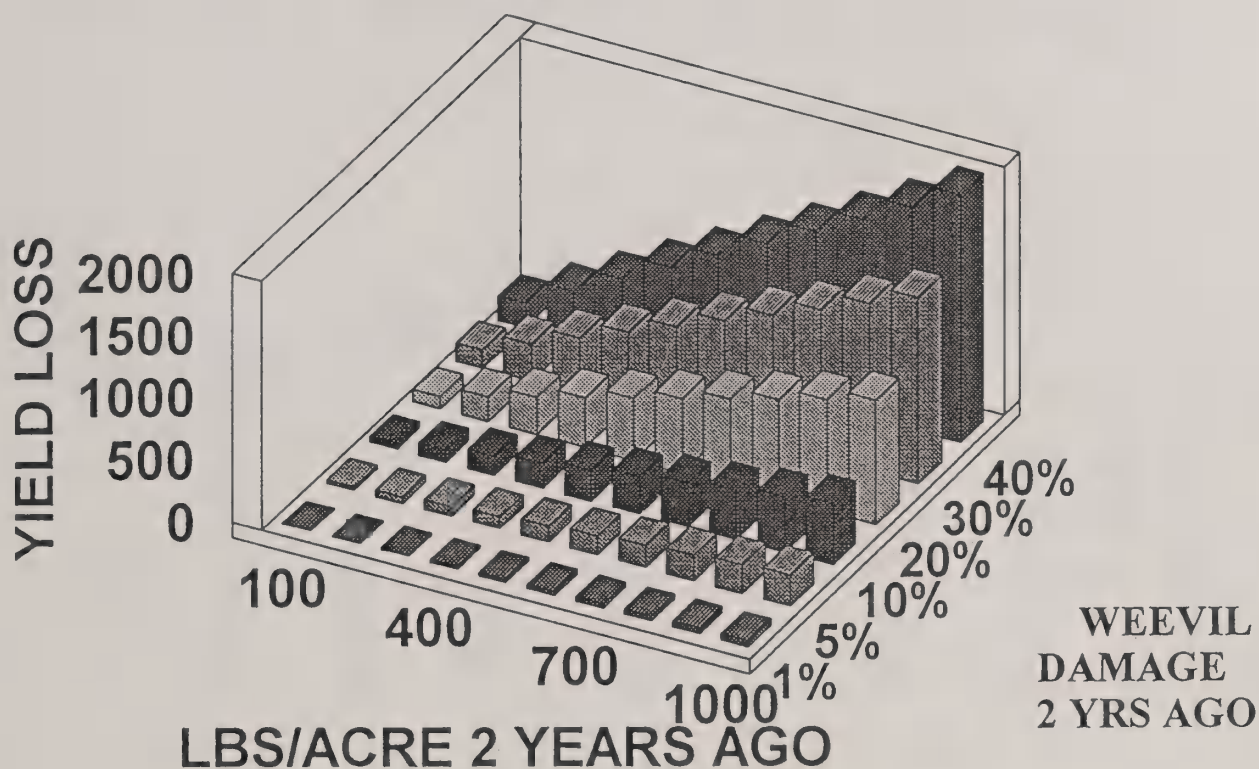
Figure 1. Expected yield losses from pecan weevil based on yield and damage experienced two years previously. Losses represent the damage capacity of the pecan weevil to the current years crop.

LOSSES CAUSED BY ONE ADULT WEEVIL
EACH ADULT DAMAGES 15 NUTS
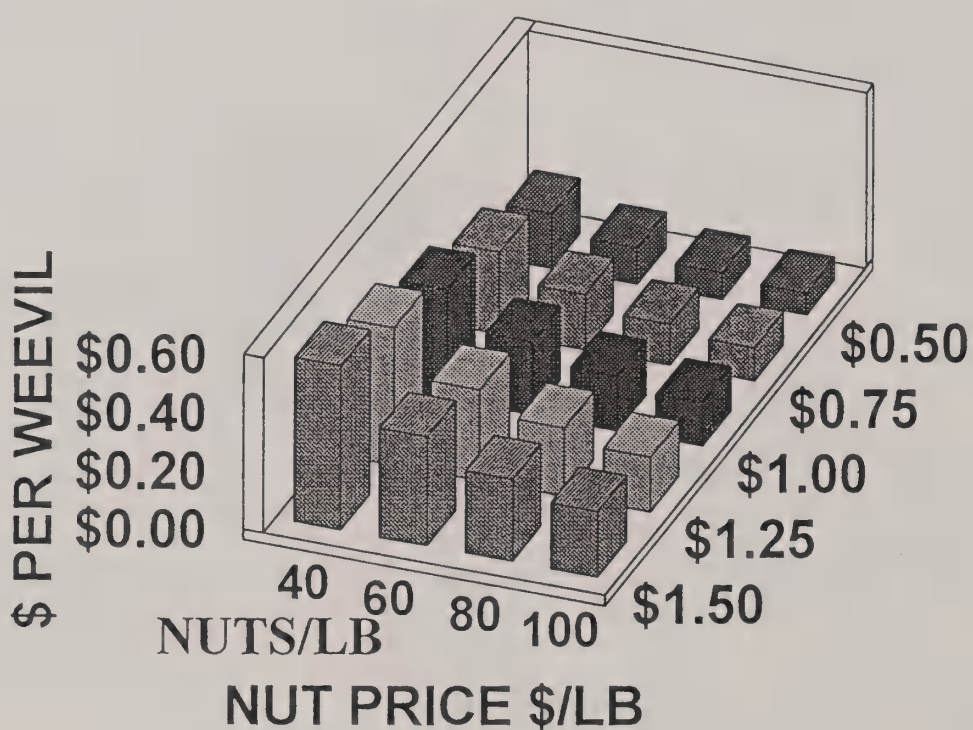
Figure 2. Each adult pecan weevil damages about 15 nuts and $ loss per weevil is shown for various nut sizes and prices.
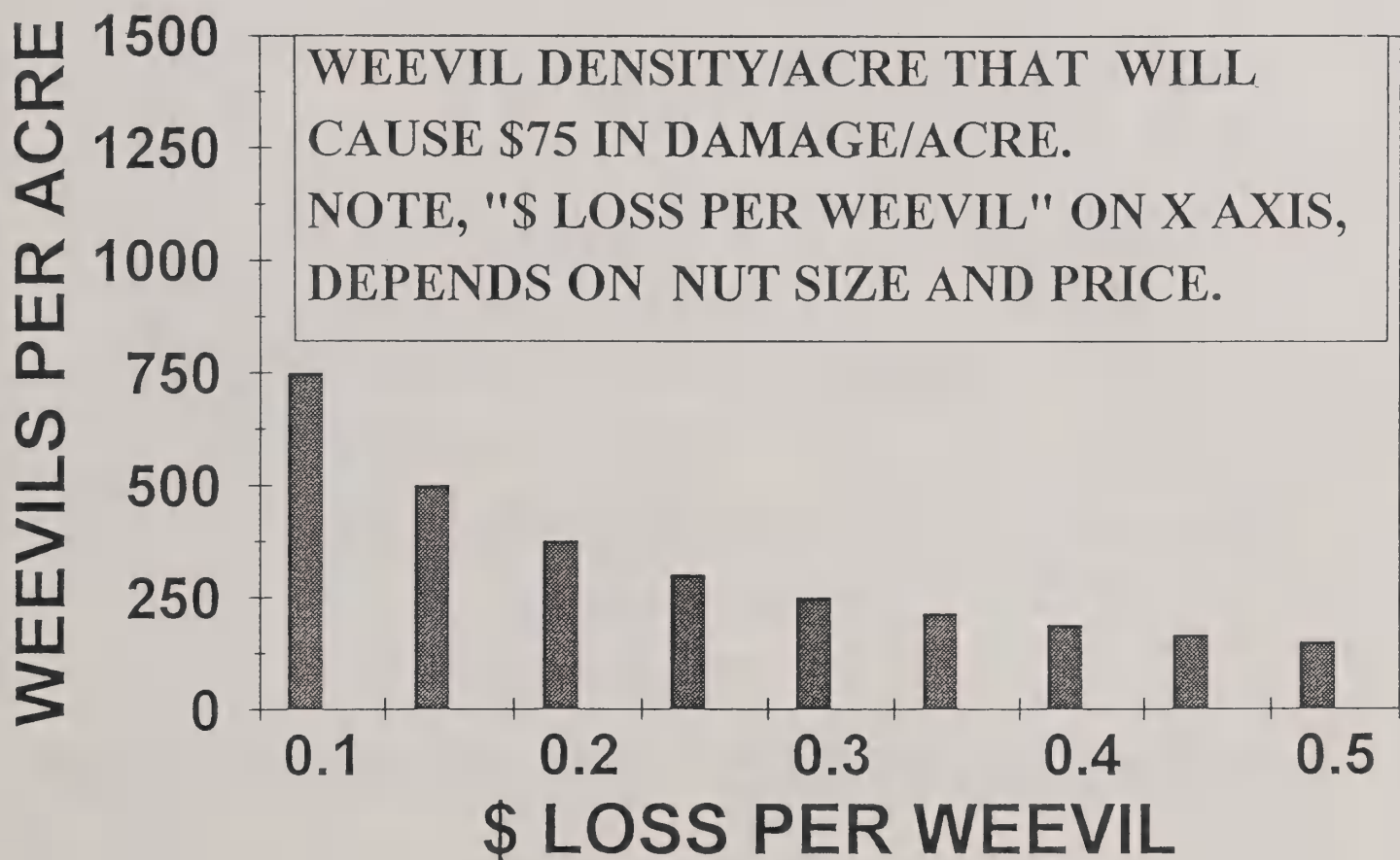
Figure 3. The minimum number of adult pecan weevils per acre required to justify management costs is compared to losses incurred per weevil, which depends on nut size and price (see Fig. 2).
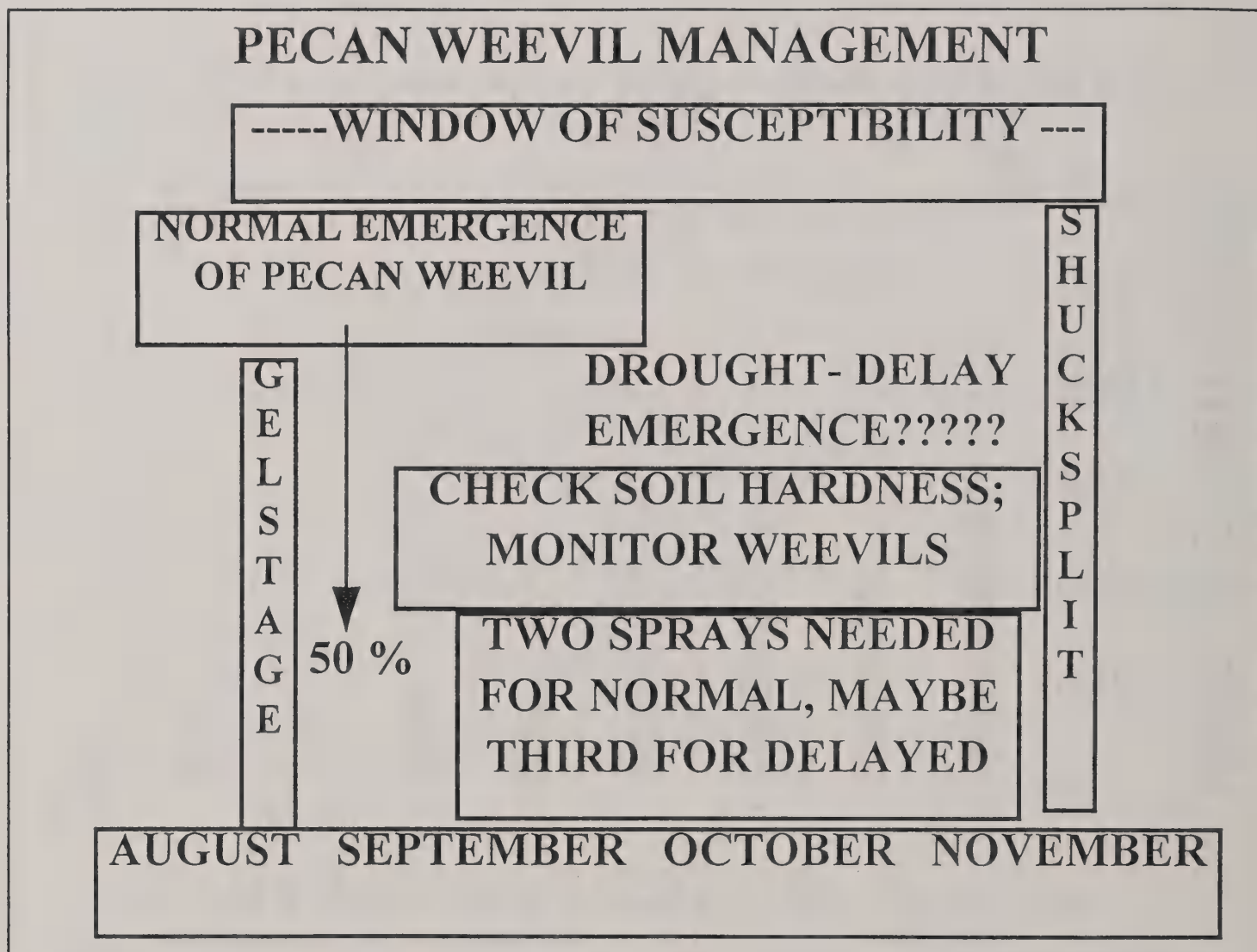
Figure 4. Pecan weevil management considerations during key periods of the season.

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┌─────────────────────────────────────────────────────────────────┐
│                  PECAN WEEVIL MANAGEMENT                          │
│                                                                   │
│  ┌────┐  ┌──────────────────────────────────────────────────┐    │
│  │    │  │ MONITOR, BEGINNING EARLY AUGUST, FOR  NUT         │    │
│  │ 1. │  │      DEVELOPMENT AND WEEVIL EMERGENCE             │    │
│  │    │  └──────────────────────────────────────────────────┘    │
│  └────┘                                                           │
│  ┌────┐  ┌────────────────────────────────────────────────┐      │
│  │    │  │ APPLY FIRST CARBARYL SPRAY WHEN NUTS AT GEL     │      │
│  │ 2. │  │   STAGE OR LATER AND WEEVILS ARE EMERGING       │      │
│  │    │  └────────────────────────────────────────────────┘      │
│  └────┘                                                           │
│  ┌────┐  ┌────────────────────────────────────────────────┐      │
│  │    │  │ IF WEEVILS CONTINUE TO EMERGE 5+ DAYS AFTER     │      │
│  │ 3. │  │ TREATMENT, TREAT AGAIN BY 12TH DAY.  REPEAT AS  │      │
│  │    │  │    NEEDED ( 3 SPRAYS USUALLY ENOUGH)            │      │
│  └────┘  └────────────────────────────────────────────────┘      │
│                        ┌────────────────────────────┐             │
│                        │   CHECK SOIL HARDNESS;      │             │
│                        │     MONITOR WEEVILS         │             │
│                        └────────────────────────────┘             │
│   ┌──────────────────────────────────────────────────────┐       │
│   │ AUGUST  SEPTEMBER  OCTOBER  NOVEMBER                  │       │
│   └──────────────────────────────────────────────────────┘       │
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Figure 5. Pecan weevil monitoring and spray timing factors for treating and retreating.

GENERAL IDEAS ABOUT GENETIC IMPROVEMENT IN PECAN

Tommy E. Thompson and L. J. Grauke[1]

This paper presents ideology concerning genetics and breeding of pecan [*Carya illinoinensis* (Wangenh.) K. Koch]. The ideas presented here are meant to stimulate discussion and concept development that will contribute to pecan genetic improvement. Most plant breeders operate on some genetic frontiers that are unproved and often unresearched by scientists in other academic areas of plant research.

Pecan genetic improvement remains a long-term breeding process. Success will continue to come from organized programs that allow parental selection, crossing, and systematic long-range testing of known-parentage clones. The idea that the perfect cultivar exists in native stands or will be discovered in random trees in orchards or yards is less and less true as requirements for cultivars that combine all desirable genetic characteristics are an absolute requirement for profitable pecan production. Future orchards will require improved cultivars and high levels of management for profitability as they do today.

As production expenses continue to escalate, pecan cultivars with low productivity, small nut size (more than 80 or so per pound), or low percent kernel (less than about 40%) will continually be eliminated from production. This elimination process has been continuous in the pecan industry since its inception. It is economically driven since producers of native pecans (or any cultivar that produces nuts similar to the low percent kernel and small size of natives) receive about 33 cents per pound less compared to improved (Fig. 1). This lower return per acre means owners cannot economically manage these stands. Production of natives has declined severely in Arkansas, Mississippi, Texas, and to some extent in Oklahoma (Grauke, Thompson, and Marquard, 1995).

Genetically, we are moving pecan away from being a native. That is, more and more, we can classify cultivars empirically based upon percent kernel, nut size, and time of nut maturity; and without knowing their origin. In the future, native and other random clone selections will be useful mainly as germplasm sources of disease and insect resistance and early nut maturity. They will be crossed with improved cultivars and other selected clones to produce improved cultivars with adequate genetics for yield, precocity, nut quality, disease and insect resistance, etc.

The current interest in selecting new cultivars with ultrahigh levels of disease and insect resistance, and without high selection pressure on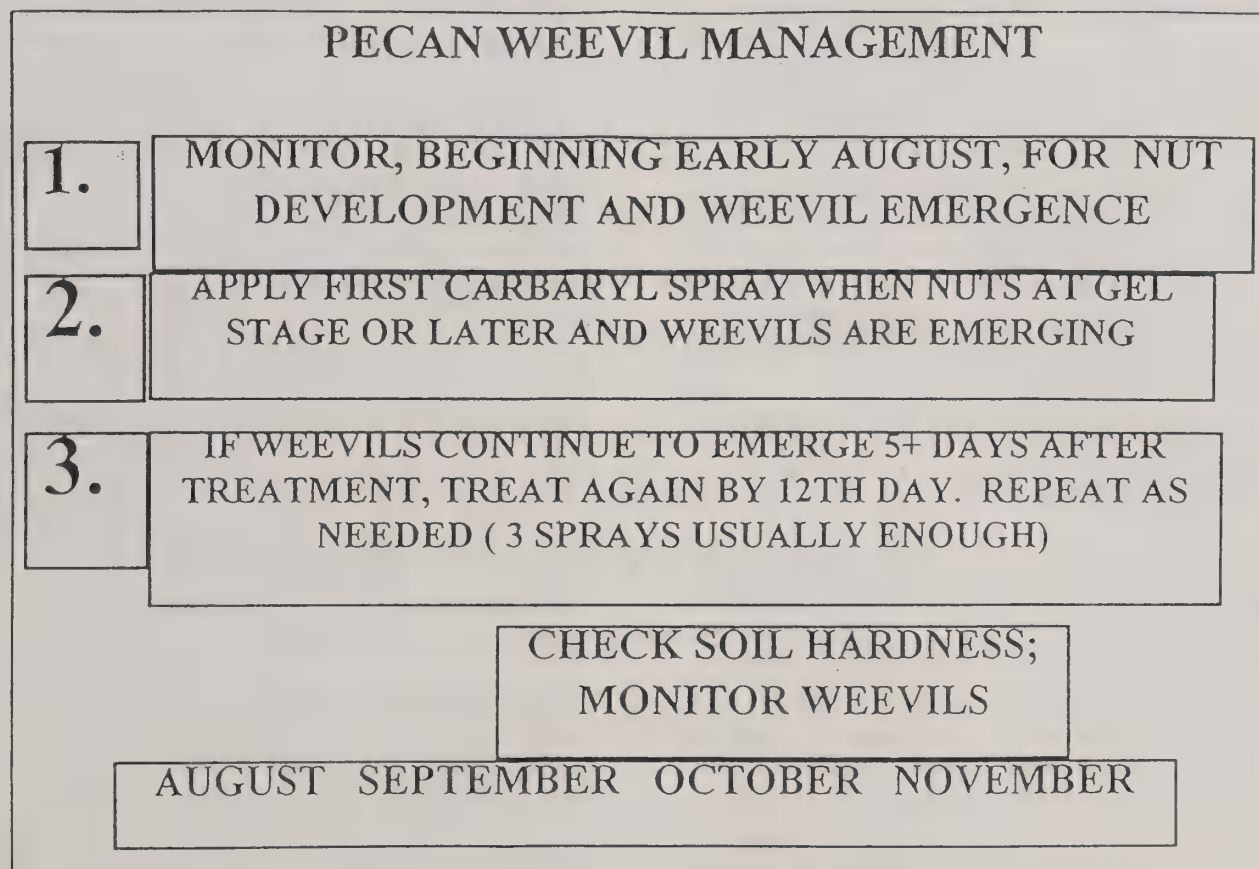 nut quality parameters and yield is unrealistic. Selection pressure for disease resistance is excellent to produce parental material useful in the crossing operation to produce new cultivars, but growers cannot afford to plant such clones as new cultivars. We remain very interested in such clones as sources of disease resistance and other traits. These clones will continue to be used as parental material to combine with the superior yieldability, nut quality, earliness, etc. of current cultivars and clones.

Currently the most neglected area of pecan science is the testing of new clones and cultivars. This is the obvious way to increase profitability, protect the environment from chemical pollutants, and thus place pecan culture more in sink with current valid environmental demands by the public at large. State cultivar recommendations, in many instances aren't sufficiently based upon current research results.

The largest pecan producing areas of the southeast rely largely upon old cultivars with obviously inferior nut quality and (or) yieldability. As a result, nut quality and production levels are not what they should be. Figure 2 shows the average cultivar age for different states. Generally, the western states have newer cultivars. New Mexico is an exception due to its large plantings of 'Western', an older cultivar. The use of old cultivars in the Southeast is one reason why pecans sell for less per pound in this area. The average price per pound of all pecans produced in Georgia during the last ten years is about 18 cents below the Texas price (Fig. 3). Considering only improved pecans Fig. 4), the average price for the last ten years is about cents greater in Texas. These price differentials are generally true for the main pecan producing areas of the southeast, compared to western production.

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Therefore, the testing and utilization of improved USDA cultivars in the Southeast is way overdue. 'Stuart' is a good example of an old cultivar that should not be recommended anywhere. The production data has shown for years how lacking this cultivar is as far as production and nut quality. The idea that it performs better as an older tree has also been disproved. Yet, even today, it is still recommended in many southeastern states. It is one thing to manage 'Stuart' orchards and orchards with other old cultivars. This is often good economic sense. It is quite another thing to still recommend these inferior cultivars for planting new orchards. As has always been the case, recommendations should be based upon production data.

Unfortunately, 'Sioux' and 'Caddo' remain largely unused in the Southeastern U.S. The traditional ideology was that these cultivars produced nuts too small to consider in commercial production. Recently, the utility and value of these cultivars in the Southeast is becoming apparent. The scab resistance of these two is excellent, and both have nut quality that is unexcelled.

In Ray Worley's test at Tifton, Georgia (Worley, 1997), 'Caddo' produced pecans worth $463 per acre through the 17th year, compared to $163 for 'Desirable' and $82 for 'Stuart'. Yet 'Stuart' continues to be recommended in parts of the Southeastern U.S. We also have not seen data that shows that 'Stuart' becomes much more profitable as tree age increases. 'Desirable' is a good cultivar in some areas, but it will soon be replaced by improved cultivars. In our own NPACTS (National Pecan Advanced Clone Testing System) tests at College Station, Texas, 'Pawnee' has outyielded 'Desirable' everywhere it has been tested. 'Pawnee' also has similar nut quality and superior yellow and black aphid resistance. Plus 'Pawnee' is not equaled by any other cultivar in producing such a high quality nut marketable during Sept. Thus 'Pawnee' is currently one of the most popular cultivars as far as number of trees being planted in the pecan industry.

Other scab-resistant USDA cultivars continue to perform well in the Southeast, especially 'Oconee'. 'Kanza' is a new USDA cultivar that has excellent scab resistance and should be adapted to the Southeast.

The USDA pecan breeding program continues to produce scab-resistant cultivars and NPACTS

clones to test in the Southeast. Controlled-cross seedlings in the Basic Breeding Program at College Station, Texas are not sprayed with a fungicide and are rated for scab resistance each year. College Station's climate is similar to the most concentrated pecan production area in the U.S. near Albany, Georgia, and is a high scab area. Therefore, the location of this breeding site is conducive to the selection of scab resistant cultivars.

Table 1 shows a few of the many NPACTS scab-resistant clones that are currently under test in Texas and at some other NPACTS locations. It is important to point out that all these clones are products of a systematic, long-range breeding program and have been evaluated over multiple years and preselected for nut and tree quality parameters. Therefore, they have a much greater chance of becoming important new cultivars.

'Western' has come and gone in its area of initial use (Central Texas). In production tests at Brownwood, Texas; it yielded only 39% of 'Wichita' and produced nut quality inferior to 'Wichita' (Thompson, et al. 191981; Thompson and Hunter, 1983). It is not even considered a realistic check cultivar in production tests now in the Central Texas area. Scab problems on 'Western' have also escalated in this area recently, and 'Western' is much more susceptible than 'Wichita'.

From a breeding standpoint, alternate bearing is still the largest problem. The question is how to genetically design a pecan tree to produce a large crop and insure that the tree will set another heavy crop the next spring. The reason for alternate bearing was obvious to pecan scientists in the 1930s (Crane et al. 1934, Smith and Waugh 1938). We are convinced that we can circumvent this problem by developing early nut maturing cultivars that have a window of opportunity to replenish CHO reserves between nut maturity and leaf dehiscence each season.

We believe cultivars of the future must have the unique genetic characteristics of early nut maturity combined with other desirable characteristics. Early nut maturity will be an absolute requirement to prevent alternate bearing by allowing tree energy rebound each season. Such clones do not currently exist in nature nor will they ever likely be produced by accident in nature. They must developed over time in a well-planned breeding program.

As pecan researchers, we must place much more emphasis on testing new pecan genetic material. We must also continually evaluate and update recommendations based on the latest test results.

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Table 1. USDA NPACTS clones with high levels of scab resistance.

| Clone	Parentage	% Kernel	Nuts/Lb.	Shucksplit
70-03-0034	ShoshoniXCheyenne	57	46	10-18
72-05-0058	OsageXCheyenne	51	59	10-02
72-06-0009	Shoshoni(BrakeXSioux)	55	53	09-20
74-05-0055	CheyenneXSioux	56	44	10-12
74-05-0060	CheyenneXSioux	58	56	10-28
77-21-0003	CreekXCape Fear	55	47	10-07
82-17-0680	Wichita Open Pollinated	58	55	09-27
82-17-1316	Wichita Open Pollinated	54	54	10-09
82-17-1614	Wichita Open Pollinated	63	55	09-27
86-02-2645	WichitaXPawnee	64	52	10-05
86-03-0008	CheyenneXPawnee	61	49	09-28
86-03-0040	CheyenneXPawnee	62	52	10-07
86-03-0624	CheyenneXPawnee	62	43	09-25
86-03-0627	CheyenneXPawnee	62	47	09-30
87-01-0016	CheyenneXPawnee	61	52	10-01
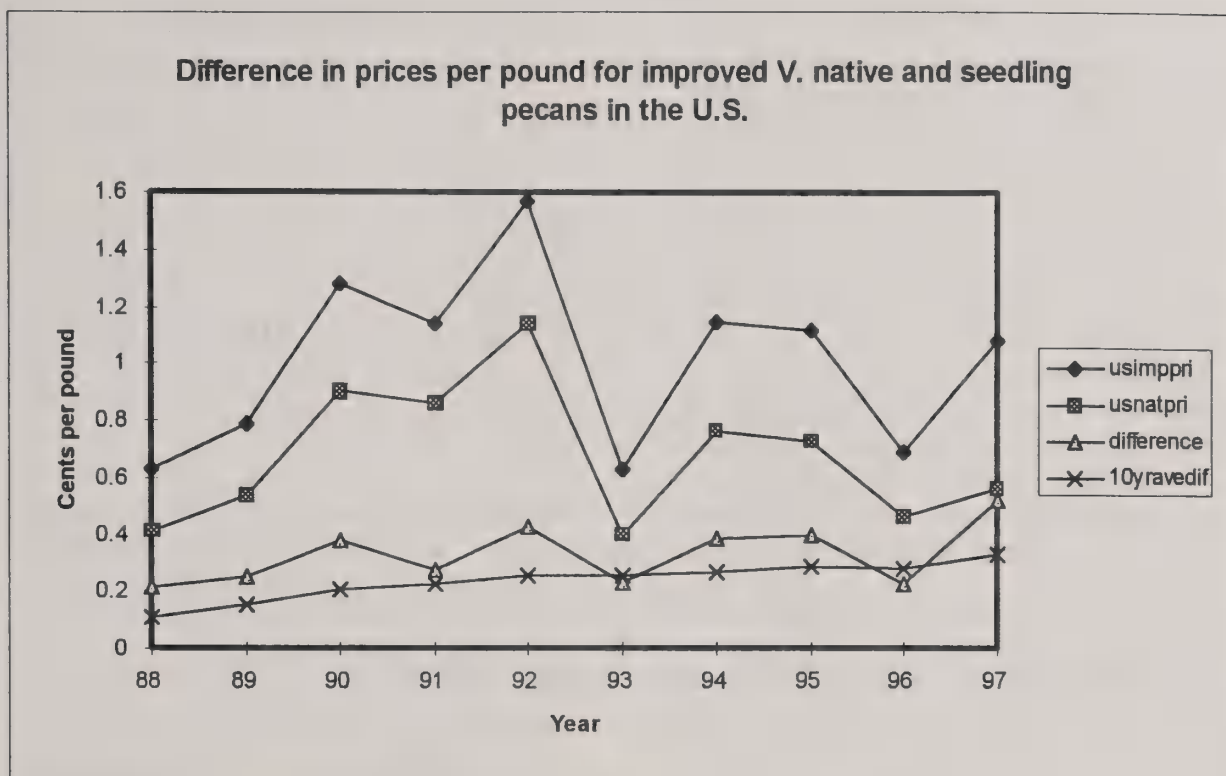
Fig. 1. Differences in prices paid per pound for improved V. native and seedling pecans in the U.S.
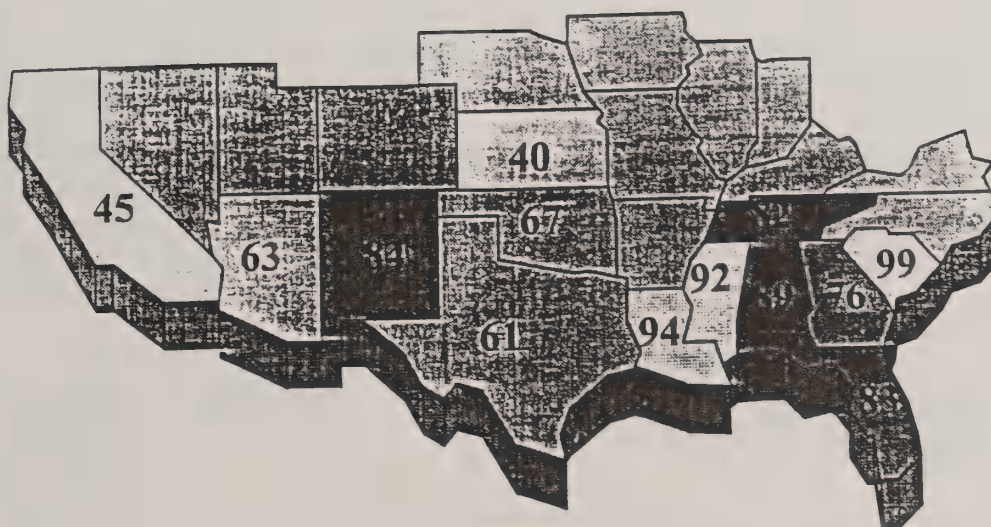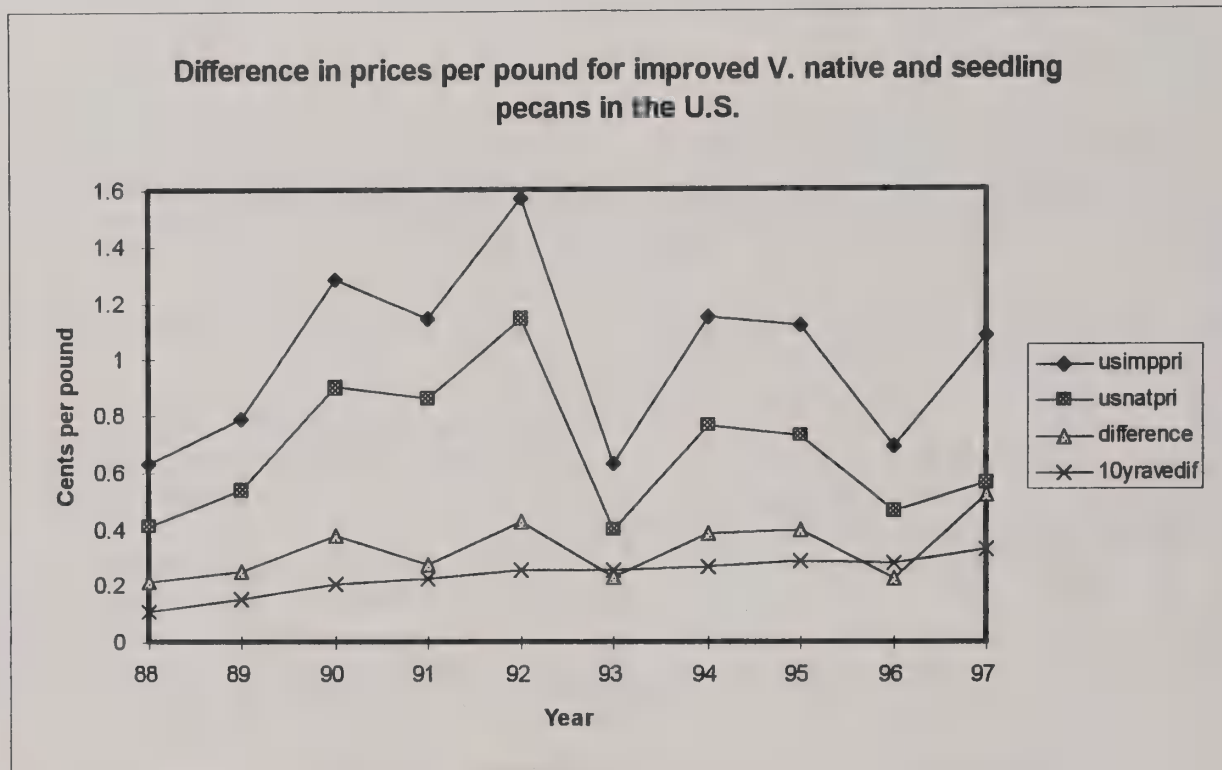

Fig. 2. Average pecan cultivar age by state.

Fig. 3. Differences in prices paid for all pecans in Texas and Georgia.
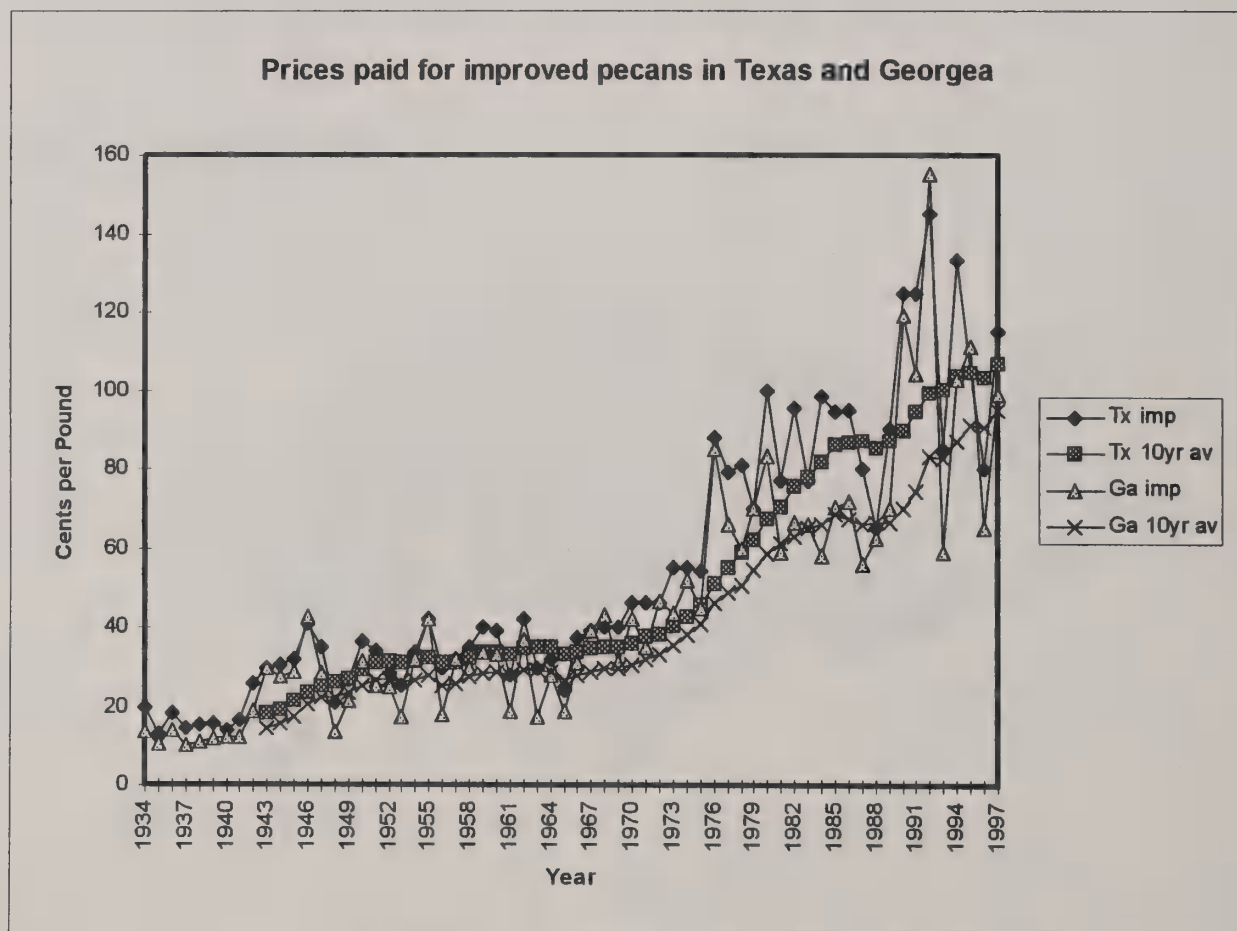

Fig. 4. Differences in prices paid for improved pecans in Georgia compared toTexas.

PEST RESISTANT CULTIVARS AS A WAY TO REDUCE INPUT COSTS

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Additional index words. pecan Carya illinoensis, low-input, diseases, insects, pests, resistance

ABSTRACT

Pest resistant cultivars save money by reducing costs associated with purchase and application of pesticides and by reducing pest-related losses, and they are more environmentally friendly. Perhaps more importantly, they provide insurance against pest-related disasters. It appears, from our observations, cultivars with reliable scab resistance can be identified by challenging clones with extremely heavy scab pressure in several locations for about 3 years. Some outstanding cultivars for low-input plantings in the Southeast include Jenkins, McMillan, Esneul, Carter, Syrup Mill, and Tinker.

By growing resistant cultivars pecan growers could save $180 per acre, assuming a reduction of 10 pesticide applications @$18. Added to this savings would be the added revenue of the crop resulting from the reduction in pest damage. Perhaps more importantly, genetic resistance provides insurance against pest-related disasters. In 1994, for instance, heavy rain in late June-early July in the Southeast prevented growers from applying sprays in a timely manner, and much of that year's crop was lost to scab disease. A resistant cultivar, if the resistance were strong, would have weathered the storm with little or no scab loss. The purposes of this report are

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to 1) discuss the degree and persistence of scab resistance among cultivars we have been testing, 2) discuss the performance of 24 cultivars grown with no sprays at the Truck Crops Experiment Station of Mississippi State University at Crystal Springs, Mississippi, and 3) update our list of cultivars suggested for trial plantings for low-input orchards.

METHODS AND MATERIALS

The degree and persistence of scab resistance. Just because a cultivar doesn't show appreciable loss to scab at a particular site in a given season doesn't mean that the resistance will persist. The scab fungus exists as genetically different strains or biotypes. The fungus has the ability to develop a strain which will attack and overcome the resistance of a particular cultivar. As the resistant strain is selected for, the resistance of the cultivar breaks down, and the disease becomes a problem. The rate at which this occurs is very important, as with some cultivars, like Elliott and Barton, scab losses are uncommon decades after fairly widespread planting of the clones. On many other cultivars, resistance may be very short-lived, and a cultivar will scab badly within a year or so of planting, even though it scabbed little initially.

We have accumulated data in a standardized manner on scab resistance of hundreds of clones for the last three years. This data is presented, for a few of the clones, in the accompanying charts (Fig. 1 A-O). The charts show stem scab lesion counts for three years at several locations. Locations are indicated by a letter in the chart, and include a) the E. V. Smith Research Center near Tallassee in east central Alabama; b) Lowndesboro, Alabama; c) another field near Tallassee, Alabama, about 3 miles from site a; d) Crystal Springs, Mississippi; e) Albany, Georgia; f) Auburn, Alabama; g) Columbia, Alabama; h) Walnut Hill, Florida; i) Andalusia, Alabama; j) Dothan, Alabama; and k) Fairhope, Alabama. Stem scab lesions were counted in October on the worst foot of stem that could be found on the tree.

Performance of cultivars in low-input planting at Crystal Springs, Mississippi. An experiment established at the Truck Crops Experiment Station in Mississippi was evaluated on October 16, 1997. The trees were grafted in 1988 onto 5-year-old rootstocks, with 4-8 replications attempted of 24 selections. The trees have never been sprayed with any fungicide or insecticide, but are fertilized and

drip-irrigated. Ratings were made for stem scab, leaf scab, nut scab, foliage retention, foliage condition sooty mold accumulation, and black aphid damage spots. Additionally, yields were estimated by visual observation, harvest date was estimated, and nuts were collected from the trees that had marketable nuts. Kernel grades and nuts/pound were determined from a one-pound sample from each tree.

Update of cultivars suggested for trial planting in the Southeast. We reviewed the data included in this report, as well as much more data accumulated over the past several years, and revised our list of cultivars suggested for trial planting in low input orchards in the Southeast. Cultivars selected have a combination of good scab resistance, foliage retention, and nut quality. What is lacking on these cultivars are long-term records of yield, and long-term evaluations of the persistence of their resistance to scab. Nevertheless, we feel at this time that these cultivars have potential use and will be good performers based on what we have observed so far.

RESULTS AND DISCUSSION

The degree and persistence of scab resistance. It is obvious from our observations that cultivars vary greatly both in initial incidence of scab and in rate of progress of the disease over time. Let's look first at a standard known susceptible cultivar, Desirable (Fig. 1-A). In 1995, at location a on the chart, incidence of scab was near 0, even though this is a highly susceptible cultivar. The reasons are that scab incidence was relatively low that year, and also that this was the first time Desirable was present at that location, and strains attacking Desirable needed time to proliferate. By the second season, scab was considerably worse at site a, and was very bad at another site (b). By the third season, scab was even worse at site a, and was bad at most, but not all, locations we observed. The mean scab for all locations and years for Desirable was 114 lesions/ft., and this mean, for reference purposes is shown on each chart by a hatched line.

Let's look next at a known highly resistant cultivar, Elliott. (Fig. 1-B). This cultivar was released about 1925 and has been planted throughout the Southeast. With Elliott, mostly scab incidence is very low. However, occasionally moderate scab is observed. the trend though doesn't suggest a progressive increase. Apparently, the mechanism(s) of resistance found in Elliott are sufficient to keep the disease in check for long periods of time with few exceptions.

Next, let's consider Cape Fear, a known cultivar of moderate susceptibility (Fig. 1-C). With Cape Fear, we only tested at one location, Byrd's Riverbend Farm. This is a 600-acre orchard planted predominately to Cape Fear, and we left Cape Fear trees as a check cultivar in a field where we established a test by topworking. So, the Cape Fear trees had been there for 10 years or so in near-monoculture allowing plenty of time for strains to develop. Thus even in the first season we observed, scab incidence was extreme on this cultivar under the severe conditions at this location.

Now let's move to a group of cultivars which we initially felt were promising in scab resistance, but which we now see are not. These examples are PeCou II (Fig. 1-D) and Scarbough (Fig. 1-E). PeCou II is a native tree from Pointe Coupee parish in Louisiana. The parent trees has produced regular crops for 70 or more years, with little incidence of scab, so some degree of resistance is apparent. However, when we put several trees of this clone in the same place for three years, scab increased considerably, as with location a on the figure. And in locations b and d, scab was bad the first year we observed (1997). With Scarbough (Fig. 1-E), also, we see appreciable scab with occasional trees attacked very severely.

Now lets consider a group of cultivars that mostly have had incidence of scab to be very low, but occasional trees are observed with moderate incidence. These include Tinker, Esneul, Creek, McMillan, Dixie, Carter, and Hughes (Fig 1.F-L). These clones bear further watching. While the breakouts of scab to moderate levels are the cause of some concern, even Elliott has such instances, and yet the scab resistance has held for the most part for many years.

The final group, the best group with regard to the disease resistance, includes Jenkins, Syrup Mill, and Barton (Fig. 1, M, N, O). These three clones have been very consistent over locations and years, with scab at none or very low with no exceptions.

Performance of cultivars in low-input planting at Crystal Springs, Mississippi. Kernel grades and nuts/lb. are shown in Table 1 for these cultivars that produced enough crop to provide a sample for grading. Highest percent edible kernel, and highest percent of #1 kernels was from Jenkins. Only four cultivars, Jenkins, Carter, Haney, and Forkert produced a kernel percentage of over 45% under the

unsprayed conditions of this test.

Table 2 shows scab incidence. Nut scab was least on Jenkins. Incidence of nut scab was higher than 50% on 17 clones.

Table 3 indicates foliage ratings. These are an indirect reflection of resistance to foliage diseases and defoliating insects. Highest percent foliage was with Jenkins.

Table 4 shows estimated yield and estimated harvest date. Yields of over 15 pounds per tree were produced on Carr, Carter, Jenkins, Hughes, and Jubilee.

We believe that Jenkins and Carter are the best clones in the experiment, with Jenkins in particular having superior potential.

Update of cultivars suggested for trial planting in the Southeast. In 1996, we listed McMillan, Tinker, Jenkins (syn. Jenkins 1, Alabama Jenkins), Pointe Coupee #2 (syn. PeCou II) Dixie, Creek, Esneul, and Barton for trial plantings for low input orchards. Following observations in 1997, we believe that Pecou II and Dixie should be removed from consideration, as PeCou II experienced almost total crop loss from scab at Crystal Springs, and scab was bad elsewhere. Dixie had low kernel grades and very small nut size at Crystal Springs, and several instances of scab lesion counts exceeding 200 at Lowndesboro, Alabama. We are adding Syrup Mill and Carter. Syrup Mill has had exceptional scab resistance, and Carter has performed well in the Crystal Springs test. Our revised list, then, is McMillan, Tinker, Jenkins, Creek, Esneul, Barton, Syrup Mill, and Carter. Barton and Creek should only be planted by those who intend to thin the crop, as they overbear badly and nut quality is unacceptable when they overload. Also, for Creek and Barton, irrigation should be provided to help in filling the nuts.

Fig. 1 (A-O). Occurrence of stem scab lesions on several pecan cultivars for three years at various locations. Letters in chart represent locations. Ratings were made in October of each year, by counting stem scab lesions on the worst foot of shoot growth on the tree. Location codes are as follows a) the E. V. Smith Research Center near Tallassee in east central Alabama; b) Lowndesboro, Alabama; c) another field near Tallassee, Alabama, about 3 miles from site a; d) Crystal Springs, Mississippi; e) Albany, Georgia; f) Auburn, Alabama; g) Columbia, Alabama; h) Walnut Hill, Florida; i) Andalusia, Alabama; j) Dothan, Alabama; and k) Fairhope, Alabama. A lower case letter (a) represents one tree. An uppercase letter (A) represents 10 trees. The hatched lines represent the means of Desirable (scab susceptible check) and Elliott (scab resistant check) at all locations and years.

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Fig. 1 (A-O). Occurrence of stem scab lesions on several pecan cultivars for three years at various locations. Letters in chart represent locations. Ratings were made in October of each year, by counting stem scab lesions on the worst foot of shoot growth on the tree. Location codes are as follows a) the E. V. Smith Research Center near Tallassee in east central Alabama; b) Lowndesboro, Alabama; c) another field near Tallassee, Alabama, about 3 miles from site a; d) Crystal Springs, Mississippi; e) Albany, Georgia; f) Auburn, Alabama; g) Columbia, Alabama; h) Walnut Hill, Florida; i) Andalusia, Alabama; j) Dothan, Alabama; and k) Fairhope, Alabama. A lower case letter (a) represents one tree. An uppercase letter (A) represents 10 trees. The hatched lines represent the means of Desirable (scab susceptible check) and Elliott (scab resistant check) at all locations and years.

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Fig. 1 (A–O). Occurrence of stem scab lesions on several pecan cultivars for three years at various locations. Letters in chart represent locations. Ratings were made in October of each year, by counting stem scab lesions on the worst foot of shoot growth on the tree. Location codes are as follows a) the E. V. Smith Research Center near Tallassee in east central Alabama; b) Lowndesboro, Alabama; c) another field near Tallassee, Alabama, about 3 miles from site a; d) Crystal Springs, Mississippi; e) Albany, Georgia; f) Auburn, Alabama; g) Columbia, Alabama; h) Walnut Hill, Florida; i) Andalusia, Alabama; j) Dothan, Alabama; and k) Fairhope, Alabama. A lower case letter (a) represents one tree. An uppercase letter (A) represents 10 trees. The hatched lines represent the means of Desirable (scab susceptible check) and Elliott (scab resistant check) at all locations and years.
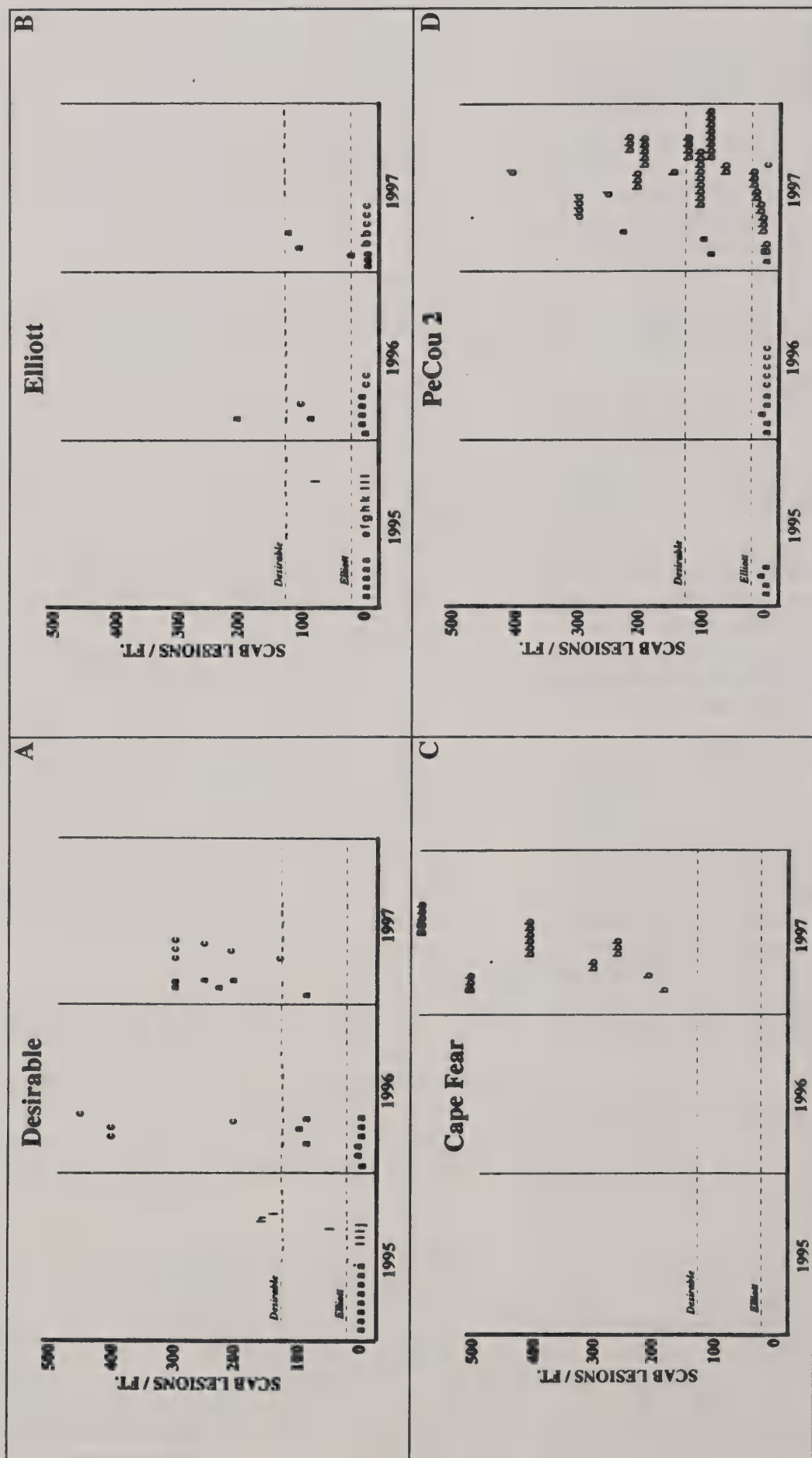
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Fig. 1 (A-O). Occurrence of stem scab lesions on several pecan cultivars for three years at various locations. Letters in chart represent locations. Ratings were made in October of each year, by counting stem scab lesions on the worst foot of shoot growth on the tree. Location codes are as follows a) the E. V. Smith Research Center near Tallassee in east central Alabama; b) Lowndesboro, Alabama; c) another field near Tallassee, Alabama, about 3 miles from site a; d) Crystal Springs, Mississippi; e) Albany, Georgia; f) Auburn, Alabama; g) Columbia, Alabama; h) Walnut Hill, Florida; i) Andalusia, Alabama; j) Dothan, Alabama; and k) Fairhope, Alabama. A lower case letter (a) represents one tree. An uppercase letter (A) represents 10 trees. The hatched lines represent the means of Desirable (scab susceptible check) and Elliott (scab resistant check) at all locations and years.
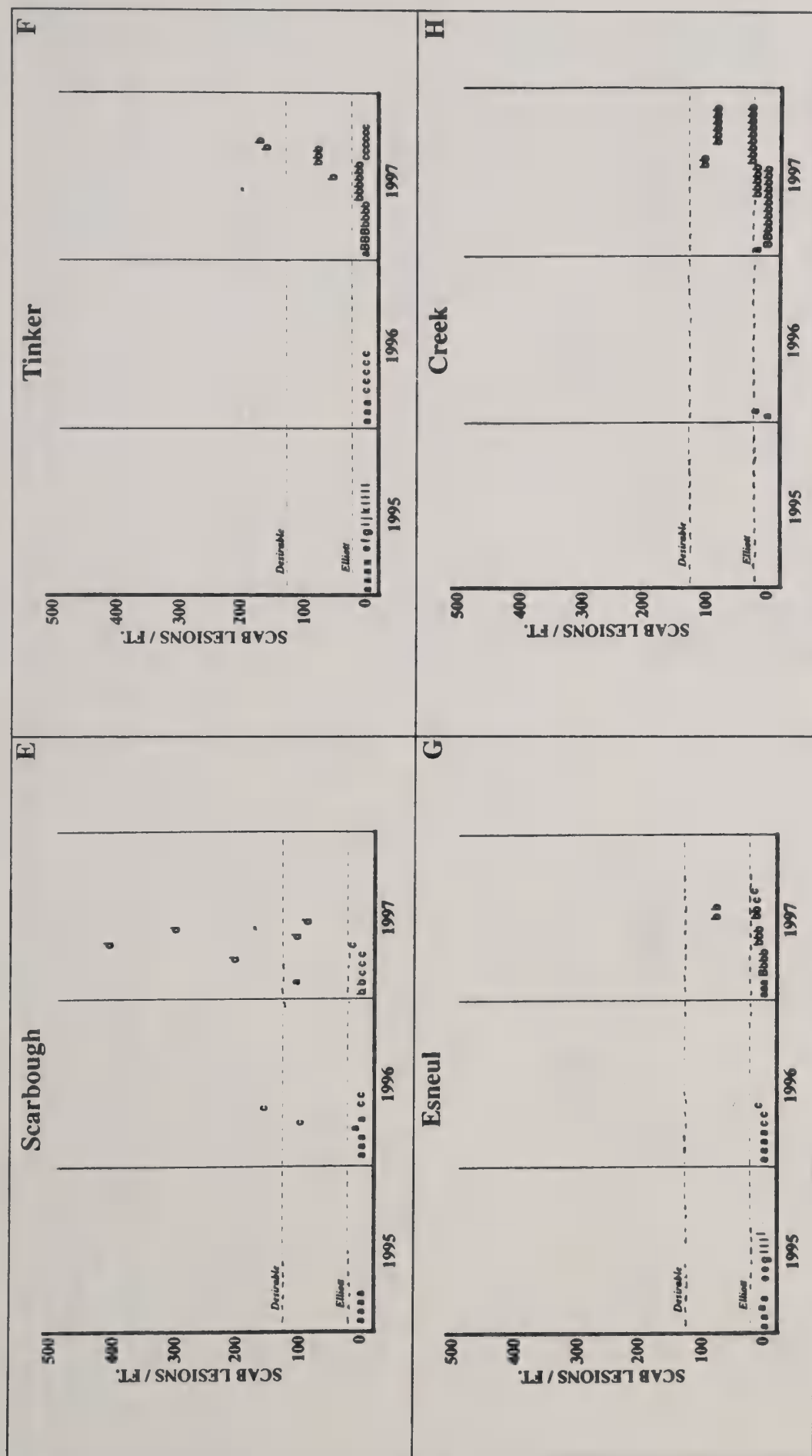
Table 1: Kernel grades and nuts/lb. of pecan cultivars or selections at Crystal Springs, Mississippi, 1997. Cultivars not shown had insufficent nuts to provide a sample.

| Cultivar | Kernel grades (%) | | | | | Nuts/lb |
	#1	#2	#3	Reject	Edible-kernel	
Jenkins	49.9 a	1.6 f	1.1 a	2.6 a	52.6 a	63 d
Forkert	37.2 abc	12.1 bcdef	2.6 a	3.7 a	51.9 ab	118 a
Haney	23.7 abcd	22.5 abcd	0.0 a	2.5 a	46.2 ab	55 d
Carter	42.6 ab	3.2 f	0.1 a	4.1 a	45.9 ab	59 d
Davis	4.5 d	36.1 a	3.9 a	1.6 a	44.4 ab	65 d
Hughes	24.6 abcd	12.6 bcdef	5.4 a	1.1 a	42.6 ab	68 cd
Dixie	11.3 cd	24.3 abc	6.3 a	4.8 a	41.9 ab	95 ab
Yawn School	35.4 abc	6.3 ef	0.0 a	0.0 a	41.7 ab	80 bcd
PeCou 2	20.2 bcd	19.7 bcde	1.7 a	2.2 a	41.6 ab	97 ab
Carr	26.2 abcd	10.3 cdef	4.9 a	2.4 a	41.4 ab	70 cd
Jubilee	29.1 abcd	8.5 def	1.7 a	6.8 a	39.4 b	58 d

Table 2. Occurrence of scab on pecan cultivars at Crystal Springs Mississippi, 1997.

Cultivar	Stem scab lesions on worst ft.	Leaf scab % on worst leaflet	Nut scab % on worst nut
Jenkins	0 f	6 ef	4 e
Dixie	7 f	3 f	8 e
Carter	6 f	2 f	9 e
Yawn School	0 f	0 f	20 de
Carr	9 f	0 f	20 de
Jubilee	0 f	0 f	27 de
Haney	28 ef	0 f	32 cde
Hughes	2 f	6 ef	41 cd
Davis	122 cdef	20 efd	84 ab
Moreland	140 cde	50 abc	90 a
Owens	178 bcd	46 abcd	96 a
Scarbough	216 abc	28 bcdef	96 a
Cherryle	173 bcd	33 abcde	97 a
Texas	80 def	24 cdef	97 a
Forkert	290 ab	52 abc	99 a
Oconee	240 abc	46 abcd	99 a
PeCou 2	308 a	40 abcd	99 a
Choctaw	224 abc	55 ab	100 a
King	310 a	54 ab	100 a
Surprise	90 def	27 bcdef	100 a
Thorton	220 abc	60 a	100 a

Table 2. Occurrence of scab on pecan cultivars at Crystal Springs Mississippi, 1997.

Table 3. Foliage condition ratings for cultivars at Crystal Springs Mississippi, 1997

Cultivar	% foliage[z]	Foliage condition (1-10, 10=best)	Sooty mold (1-10, 10=worst)	Black aphid Spots[y]
Jenkins	91 a	8.6 ab	1.2 c	13.8 abc
Moreland	85 abc	6.5 abc	2.5 abc	2.5 de
Dixie	83 abc	8.0 ab	1.3 c	1.7 e
Haney	82 abc	8.0 ab	2.7 abc	1.0 e
Carter	79 abcd	8.0 ab	1.5 bc	4.8 bcde
Hughes	78 abcd	7.6 abc	1.6 bc	1.8 e
Carr	78 abcd	7.5 abc	1.8 abc	3.2 cde
Cherryle	77 abcd	6.3 abc	2.0 abc	36.7 cde
Jubilee	77 abcd	8.3 ab	3.3 a	2.3 de
Davis	69 abcde	6.0 bc	2.4 abc	12.0 abcde
Scarbough	66 abcdef	5.0 cb	2.2 abc	17.4 a
Oconee	63 bcdef	6.2 abc	1.6 bc	17.2 a
King	60 cdef	5.1 bc	2.0 abc	3.5 cde
Forkert	56 defg	4.6 defg	3.0 ab	7.6 abcde
Owens	45 efgh	4.4 cb	2.0 abc	4.2 cde
PeCou 2	42 fgh	4.0 cb	2.3 abc	10.2 abcde
Choctaw	32 hi	3.0 bc	2.4 abc	11.6 abcde
Surprize	87 ab	7.5 abc	3.3 a	8.5 abcde
Yawn School	60 cdef	8.0 ab	2.0 abc	6.0 bcde
Texas	36 gh	3.8 cb	2.6 abc	13.0 abcd
Thorton	10 i	2.0 c	2.0 abc	2.0 de

[z]Percent foliage remaining at time of rating on October 16,1997

[y]Black aphid spots on worst compound leaflet on tree.

Table 4. Estimated harvest date and yield for pecan cultivars at Crystal Springs Mississippi, 1997

Cultivar	Estimated Harvest Date	Estimate Yield (lbs./tree)
Carr	Oct 19	20.3 a
Carter	Oct 15	19.3 ab
Hughes	Oct 27	16.8 ab
Jenkins	Oct 15	16.6 ab
Jubilee	Oct 10	15.0 ab
Haney	Oct 22	13.0 abc
Yawn School	Oct 30	12.0 bc
Dixie	Oct 13	11.3 bc
Moreland	Oct 25	6.5 cd
Scarbough	Oct 26	3.4 d
Davis	Oct 18	3.0 d
Surprise	Nov 1	1.0 d
PeCou 2	Oct 15	0.5 d
Oconee	Oct 16	0.4 d
Forkert	Oct 26	0.2 d
Owens	Oct 22	0.2 d
King	Oct 16	0.1 d
Cherryle	Oct 26	0.0 d
Choctaw	Oct 27	0.0 d
Texas	Oct 14	0.0 d
Thorton	Oct 24	0.0 d

MANAGING ROOTSTOCKS

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Additional index words. *Carya illinoinensis*, seedstocks, seedling diversity.

ABSTRACT

The genetic composition and performance of pecan seedlings (tree size and seasonal growth patterns) varies based on the geographic origin of the seedstock families. Particular seedstocks have been selected by nurserymen to optimize performance within geographic regions, and their value is demonstrable. Suggestions are offered for the continued selection of improved seedstocks. Pollen from northern cultivars delays germination and reduces growth of southern cultivars, making pollination of designated open-pollinated seedstock trees important. Growers should be aware of the seedstocks used in propagating trees for their orchards. Researchers should continue to investigate rootstock influence on tree performance to refine regional recommendations. Current knowledge of the distribution of genetic diversity within populations has implications for the maintenance and use of that diversity in conservation plantings.

INTRODUCTION

The purpose of this paper is to address critical aspects of rootstock management in an effort to offer practical suggestions for managers at different levels. Those levels include nurserymen producing grafted trees for sale, pecan growers planning and planting new orchards, growers with established orchards, researchers establishing test orchards, and regional planners involved with the maintenance of germplasm diversity on a regional or national level.

The performance of trees in the field is a function of their genetic composition, the environment (climate, soil, and associated

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organisms) at the planting site, and the culture that we as managers bring to the mix. Given the range of climates where pecans are planted and the diversity of managerial objectives, this analysis will attempt to deal with foundation principles that can be applied to different situations.

GENETIC VARIATION ACROSS RANGE

Pecan populations vary genetically over the range of the species, with genetic variation associated with the constraints the environment places on tree survival and performance. Indirect evidence for the genetic variation in relation to seed origin can be obtained from biochemical analysis of proteins in seedlings. Isozyme analysis reveals patterns of variation in native populations that are apparently associated with geographic regions (Grauke et al., 1995). Four polymorphic loci [phosphoglucomutase (*Pgm-1*), phosphoglucose isomerase (*Pgi-2*), malate dehydrogenase (*Mdh-1*), and leucine aminopeptidase (*Lap*)] are amenable to genetic interpretation (Marquard, 1987, 1989, 1991; Marquard et al., 1995) while the fifth, diaphorase (*Dia*), was simply scored for the presence or absence of a single high band (Marquard et al., 1995). Over 170 pecan cultivars in the National Clonal Germplasm Repository (NCGR) Cultivar collection, and 745 seedlings in the NCGR Provenance collection were analyzed for the five isozymes. The D allele of Pgi-2 was found in the provenance, but not in the cultivar collection. Furthermore, the allele was found in some populations, but not in most. It was found in more than 40 trees in several western Texas populations, and was especially frequent in collections made along Lipan Creek (Tom Green County) and Devil's River (Val Verde County). The allele was also found in two seedlings arising from the same Illinois seedstock. The observation of rare alleles in native populations but not in improved selections reinforces the strategy of continued characterization of the genetic diversity of native pecan populations, especially in areas that are endangered or at the boundary of the range. For the maintenance of genetic diversity at the state level (as in Conservation Reserve Programs), multiple trees from multiple populations should be represented. If regionally specific alleles could be linked to site

adaptations, they might function as markers for selection.

Direct evidence for the genetic variation (i.e. differences in DNA) of native populations in relation to distribution can be obtained from molecular techniques based on the polymerase chain reaction (PCR). We used Amplified Fragment Length Polymorphic DNA (AFLPs) to characterize pecan seedlings, but failed to refine the procedure adequately, for reasons that will be addressed elsewhere (Grauke et al., 1998). Working with Dr. Sam Reddy at the Crop Biotechnology Center at Texas A&M University, we are currently developing a microsatellite library from 'Halbert'. We are testing the utility of primers by using them to evaluate the genetically diverse core subset. Microsatellites have the advantage of revealing heterozygotes (as do isozymes). AFLPs, on the other hand, reveal only presence or absence of a particular band. As a result, microsatellites have more precision in tracing hereditary relationships. In preliminary efforts, we have obtained excellent separation of species in the genus, interspecific hybrids, and genotypes of pecan. At least one of the initial markers developed shows allelic patterns evidently associated with geographic origin. The reproducibility of the procedure is excellent. We hope to develop genetic marker techniques associated with tree characters such as disease resistance, zinc uptake and cold hardiness to contribute to both scion and rootstock selection and breeding.

PATTERNS OF SEEDSTOCK PERFORMANCE

As those techniques are being developed, we have other evidence for the assertion that area of seed origin influences the performance of seedlings in an orchard. Seed nuts were collected from native trees in the US and Mexico in 1986-87. The collections represent 19 populations distributed from Missouri south to Oaxaca, Mexico, each represented by 3-6 seedstocks (families) (Grauke et al., 1989). At College Station, seed were planted in containers in 1988, and were transferred to a randomized block orchard in 1990. Despite the severe imbalance in the test due to poor germination and mortality, some generalizations can be made on the data.

Variation by Population
Tree size
Tree size varied in relation to latitude of seed origin , with some seed collected south of the orchard site producing the largest seedlings (Fig 1). Based on the curve generated in fitting the data, the optimum size growth for trees grown at our orchard site (30 N latitude) was obtained with seed collected at latitudes between 23 and 26 N latitude, or approximately 300 miles south.

Phenology
Common sense would dictate that seedstocks obtained relatively close to the intended orchard site should be better adapted to the climate at the site than those obtained at greater distance. Data in Table 1 help to illustrate the dynamic nature of tree response to the environment. Tree size varied between populations of origin each year, with the MX-4 (Ixmiquilpan) and TX-5 (Tom Green County) populations having smaller tree size. Some populations could be distinguished on the basis of phenology (Table 2). Some populations (e.g. MX-5, composed of 4 open-pollinated seedling families from Jaumave) were characterized by early spring growth, while others (e.g. MX-4, composed of 3 open-pollinated seedling families from Ixmiquilpan) had longer duration of growth in the fall. Freeze damage occurred to trees in both populations in some years.

In our orchard, seedlings grown from northern sources are at a distinct disadvantage on the basis of reduced vigor, while trees from far southern sources are non-adapted by altered phenology, since duration of seedling growth is also related to latitude of origin (Fig. 2). The tendency for seedlings of southern parentage to continue growth late in the fall can contribute to size increase, but exposes them to increased risk of freeze injury. The timing of severe freeze cycles in relation to orchard age will influence the success of establishment, and is not under the growers control. The grower can reduce the risk by avoiding trees from far southern sources i.e. >200 miles south of the orchard site.

Patterns of phenology have been used to distinguish unrelated open-pollinated families of seedstocks (Grauke and Pratt, 1992). The current data indicate that the shared genetic

patterns within native populations may be manifested in synchronized patterns of phenology that can be used to separate one population from another. Such patterns should be indicative of increased fitness for the environmental conditions of the area and might have an influence on adaptations of co-evolved species in those populations.

Patterns of tree growth response to an environment will include both the inception of dormancy (which has a photoperiodic component), the hardiness of the seedlings (which will be influenced by nutrition and crop load), and the chilling requirement (which may be influenced (see Smith et al., 1992) by temperature extremes as well as their duration). Differentiation of cultivars for each of those parameters should have predictive value in characterizing the families produced from their open-pollinated seed.

Methods of evaluating climatic adaptation need refinement. Currently, we monitor inception of bud growth in the spring and leaf drop in the fall. We are studying the use of differential thermal analysis and oxidative browning in response to controlled freezing to quantify differences between cultivars and seedstock families.

Rootstock effects graft phenology
Even after being grafted, the influence of rootstocks can be distinguished on the basis of phenology (Grauke and Pratt, 1992). Rootstocks that advance budbreak in the spring may expose grafts to increased damage from late spring freezes, while those that encourage late growth in the fall may incur increased damage from early fall freezes. If the zone of seedling deployment is far north of the zone of seedstock procurement, the survival of trees is at risk.

We have studied seedstock usage by nurserymen throughout the US (Grauke and Thompson, 1995). Regional patterns of seedstock selection are apparent, and result in optimum performance under local conditions. Deployment patterns change in response to local nursery closures as well as regional quarantines. In the central and eastern regions, growers should be wary of transporting seedlings more than ~200 miles north of the site of origin. In the west, variation in elevation complicates the evaluation of climate, but should be considered when choosing the rootstocks for an orchard site.

SEEDSTOCK SELECTION
Root characteristics vary in seedstocks
Nurserymen have traditionally selected seedstocks on the basis of increased seedling vigor to more quickly produce seedlings of graftable size. In an effort to improve the power of that selection, I studied the root characteristics of seedlings grown from seedstocks collected from native populations across the US range. Seed were collected in the fall of 1989, from 53 families (individual trees) in 15 populations located from Illinois to South Texas. Seed were planted in a randomized block test in a greenhouse, with 8 seed of each family (424 seed) planted in each of 4 blocks (total of 1696 seed) and each block bounded by a border row. During January after the first season's growth, stem diameter and height were measured, seedlings were removed from their containers and roots were rated on the following scales:

Tap root:
    Max. root dia.
    Diameter at 15"
    Root rank   max. dia + tip dia.
Lateral root:
    Abundance   1=abundant
                      2=medium
                      3=few
    Diameter   1=strong
                      2=medium
                      3=weak
    Length   1=long
                      2=medium
                      3=short
    Lateral rank   abund. + dia. + lngth

Populations (i.e. assemblages of multiple seedstocks from an area) are significantly different for all root characterizations (Table 3).

The root characteristics of seedlings are highly correlated with above ground seedling characteristics, especially stem diameter. Taproot maximum diameter, tip diameter and root rank (their additive function), are all highly correlated with stem diameter (Prob >|R|=.81, .74, and .81, respectively). Lateral root

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abundance, diameter, length and lateral root rank (their additive function) are also highly correlated with stem diameter (Prob >|R|=-.52, -.59, -.60, and -.71respectively). Correlations are negative, since the most beneficial lateral root rating (those with abundant, strong, long laterals) is the lowest. In this population, selection based on stem diameter would be accompanied by improved lateral root characteristics. There is some indication that the related species *Carya aquatica* might have increased numbers of lateral roots (Grauke and Pratt, 1985). Further testing should be conducted to determine the influence of species on lateral root characteristics and seedling performance.

Selection improves performance

The power of seedstock selection by nurserymen is evident in the increased size of field grown nursery seedstocks, when compared to unselected seedstocks collected across the U. S. species range (Table 4). The population labeled 'Nursery' is comprised of the seedstocks 'Burkett', 'Elliott', and 'VC-168'. The only population to maintain comparable size to the nursery selected seedstocks is an assemblage of south Louisiana seedstocks. The Brazos population was collected south of the orchard site on similar soil type, and was expected to be among the best performers. Although not statistically distinguishable from any of the larger seedstocks, the native trees in that population did not have notable vigor, as a group.

Selecting individual seedstocks

The performance of individual trees within populations is also distinguishable based on tree size (Table 5). The largest individual seedstocks were 'Elliott' and 'VC-168'. 'Elliott' seedstock has consistently performed well in the southeastern area, is a widely used nursery seedstock, and is recommended as a rootstock in Burleson County, TX where this orchard is located (Grauke, 1993). In the Shreveport area, 'Elliott' seedstock has been reported to have been damaged by early fall freezes (R. S. Sanderlin, personal communication). In our orchard, 'VC-168' seedlings were inseparable from 'Elliott' seedlings based on diameter. 'VC-168' seedlings tend to hold leaves late into the fall. This can be an advantage, but is a liability if trees are tender at first frost (as with

many Mexican seedstocks). One individual from the Brazos population (Brazos 4) performed as well as the 'Burkett' seedstock in this test.

The poorest performance in the orchard has been from seedstocks collected in Illinois, and from isolated west Texas populations (Scurry County) where inbreeding depression may be a factor.

Selection based on nut characters

Nut characteristics can be useful in predicting the performance of seedlings, both within a seedstock (Grauke and Pratt, 1985) and across different seedstocks (Grauke, 1991). Reduced kernel percentage can reduce initial seedling size by a reduction of energy for growth, independently of other genetic effects. We have reported a correlation between nut percent kernel and initial seedling size (Grauke, 1991). The kernel is the energy source for the developing seedling, and remains attached and supportive for several weeks after germination (Wetzstein et al., 1983). Nuts with greater amounts of stored energy would be expected to produce larger seedlings, given equal genetic composition. Nurserymen should select large, well-filled seed for maximum seedstock performance.

Pollen effects of seedling performance

Within a seedstock, the source of pollen can influence the seed and seedling characteristics. Romberg and Smith (1949) reported that seed produced by self-pollination had reduced kernel percentage and produced smaller seedlings than cross-pollinated seed. Pollen sources also can be distinguished by their effects on cross-pollinated seed (Marquard, 1986). 'Cape Fear' pollen used to pollinate 'Western' flowers produced nuts comparable to self-pollinated nuts. Both delayed seedling growth and reduced vigor is apparent when northern pollen is used to pollinate flowers of southern trees. In 1997, I pollinated bagged clusters on the same trees with pollen from 'NC-4' (a northern pecan cultivar), 'Pawnee' (mixed northern and southern parentage) and 'VC-168' (a southern cultivar). Open-pollinated (and unbagged) seed was also collected for comparison. Despite the low numbers of seed produced, differences were apparent in the nut characteristics (Table 6).

The southern pollen source produced nuts that had greater density (reduced buoyancy) than those produced by northern pollen. Seedlings pollinated with 'VC-168' emerged faster after planting, and in preliminary size measurements, are larger. This is consistent with the observations of Ou et al., (1994) who noted delayed germination of nuts pollinated with northern pollen and suggested that strategy of reducing preharvest germination. It is also consistent with the data of Hanna (1972), who reported delayed budbreak and reduced growth of southern seedstocks pollinated with northern pollen (author's analysis). For maximum growth and vigor of seedstocks, nurserymen in the south should insure cross-pollination of seedstock trees by a vigorous, southern-type pollinizer.

One extreme of cross-pollination is the formation of interspecific hybrids, some of which exhibit 'hybrid vigor'. The interspecific hybrid between pecan and water hickory (*Carya X lecontei*) has been used as a seedstock for pecan. Toliver and Stauder (1982) reported the hybrids to be intermediate in size between their parents, with water hickory the largest, when grown on a poorly drained site (well suited to water hickory) in Louisiana. Grauke and O'Barr (1996) reported hybrids to be intermediate in size between their parents, with pecan the largest, when grown on a well drained site (well suited to pecan) in Louisiana. We found patterns of performance in grafted trees that favored use of hybrids over the water hickory. Until we have more information on their performance, orchardists should use hybrid seed only on a prescription basis, when the intended deployment site is poorly drained. Under those conditions, the reduced profitability of a poor site should be recognized. Such sites should often be avoided entirely (Grauke, 1996).

Seedstock effects nutrition
Grauke and O'Barr (1996) noted visibly darker foliage color of 'Oconee' scions on 'Elliott' seedling rootstocks than on 'Moore' seedling rootstocks. 'Oconee' on pecan rootstocks were uniformly darker as a group than when grafted on hybrid rootstocks. Other studies have found differences in nutrient uptake due to rootstock (Grauke et al, 1989). Hanna's data indicates increased uptake of Zn in seedlings having northern maternal parentage, but no influence

due to northern pollen parentage. Since northern parents (either maternal or paternal) reduced seedling growth, the observed influence of the northern maternal parent on Zn uptake is not due merely to a concentration effect related to vigor.

Researchers establishing test orchards of pecan cultivars should be aware of the subtle differences that can be caused by different rootstocks. To avoid confounding tests where rootstock is not a variable, researchers should use a single open-pollinated seedstock as rootstock. Trees obtained from a single nurseryman are not necessarily propagated on a common rootstock, since some nurserymen use multiple seedstocks in a given year.

SUMMARY
The objectives of managers seeking to conserve genetic diversity in pecan are in conflict with the objectives of managers seeking to select increasingly uniform and specifically adapted seedstocks. For the long term development of the crop, it will be necessary to accomplish both objectives. As we improve our application of molecular tools to characterize diversity, we should gain improved appreciation for the regional diversity and adaptations of native pecan populations. The field performance (tree size, phenology, nutrient uptake) of pecan seedlings can be distinguished on the basis of population of origin, raising possibilities for seedstocks narrowly adapted to particular local environments. By coupling the improvements obtained by selection with the maintenance of diversity inherent in multiple seedstocks, managers should be able to promote conservation and utilization. Recommendations concerning management of rootstocks can be generalized for particular applications:

For nurserymen: The value of the current generation of locally adapted, selected seedstocks is apparent, and should serve as a basis for evaluating additional seedstock entries. Within any seedstock, there is value in selecting large, well filled seed. The most likely source of seedstocks with improved performance will be native populations located south of the nursery site (within about 200 miles), and on comparable soil associations. In the south, trees

maintained as sources of seedstock should be pollinated by compatible, vigorous, southern cultivars, rather than by northern cultivars. In the north, seedstock trees will probably be pollinated by natives, but should not be pollinated by southern cultivars. Selection on the basis of stem diameter will apparently accomplish selection for several root characters, although attention should be paid to lateral root formation at digging. For markets more than 200 miles north of the nursery site, nurserymen should grow hardy seedstocks.

For growers: Growers establishing new orchards should purchase nursery stock as close as possible to the orchard site. They should know which seedstock(s) was used for rootstock production, and the reasons for its use. If trees are purchased from a nursery more than ~200 miles south of the orchard site, trees should be on a rootstock known to be hardy. In the west, orchard elevation reduces the duration of the growing season and should be carefully evaluated when choosing both rootstock and scion cultivars. Care should also be exercised when moving stock on an east-west axis since the western native pecan populations may have increased ability to take up Zn from alkaline soils, while eastern stocks may have adaptation to more acidic soils. The common eastern stocks should be used with caution west of Texas, while western stocks should be used with caution east of Texas. In the southeast, hybrid rootstocks should be preferred over water hickory, but should be used only when site limitations dictate.

For researchers: Test orchards should control the variable of rootstock, either by using a single open-pollinated seedstock for rootstock production, or by incorporating multiple seedstocks as test variables. Test orchards should be established that bracket the known variability of rootstocks on east-west and north-south axes. Methods of evaluating chilling requirement and hardiness should be refined and applied. Variation in the uptake of nutrient elements as a function of rootstock should be studied, with the constraints of the orchard site being carefully considered in test establishment.

For regional conservationists: Pecan seedlings vary in isozyme composition and performance

within geographic populations. To maximize diversity and maintain regional adaptation in state conservation plantings, multiple populations within the state (preferably from widely separated river systems) should be visited in procuring seed. Deployment of seedlings should be to areas in the vicinity and to within 200 miles north of the zone of procurement. If increased performance in either tree or nut characteristics is desired, multiple seedstocks can be planted from climatically adapted local selections. The number of seedstocks to target and methods of selection are being refined. When germplasm collections are held in stands with accessions from mixed provenances, the seed from any accession will be less predictable in its performance due to pollination from widely divergent sources. This might justify the establishment of designated regional seedstock banks for use in particular geographic regions.

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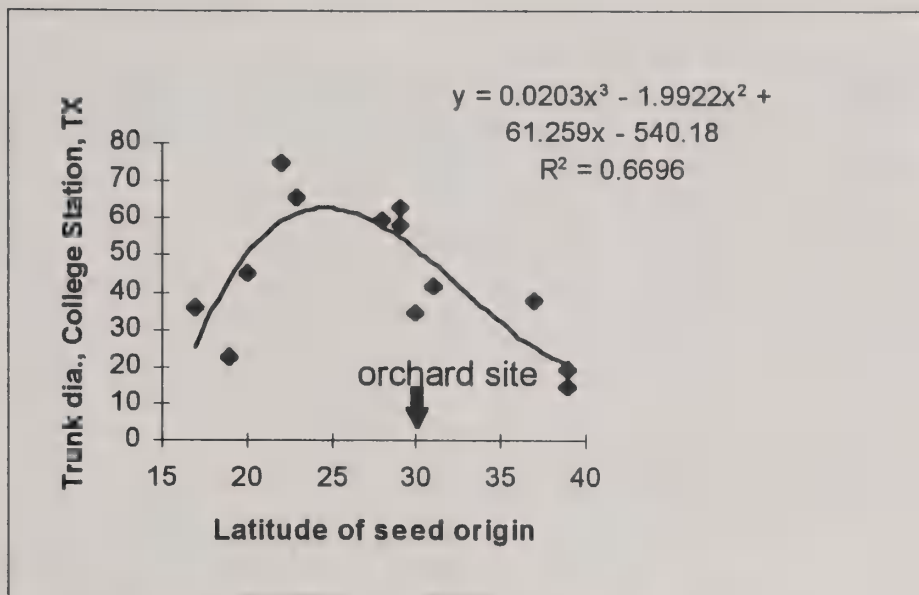
Figure 1. The relationship between latitude of seed origin
to seedling trunk diameters.
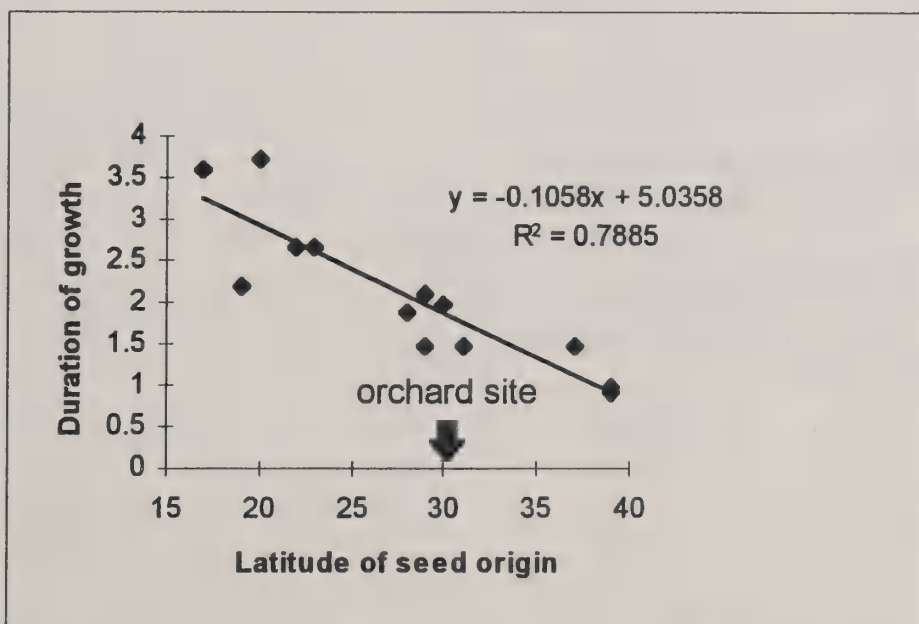
Figure 2. The relationship between latitude of seed origin and duration
of growth. Duration of growth rated 12/4/96 on scale: 1=total defoliation,
2=>50% to 99% leaf drop, 3= 0 to 50% drop, 4=active growth.

Table 1. Patterns of seedling size as influenced by population of seed origin.				
Pop	No. of families	Diameter (cm) 3/1996	Diameter (cm) 3/1997	Diameter (cm) 1/1998
MX-1	2	7.5 a[z]	10.1 a	12.9 a
MX-5	4	6.2 a	8.5 a	11.5 a
TX-1	3	6.2 a	8.6 a	11.2 a
TX-2	2	6.0 ab	8.1 ab	10.5 a
MX-4	3	4.5 bc	5.1 c	6.8 b
TX-5	5	4.0 c	6.0 bc	7.8 b
[z]Mean separation by paired t test. Ratings with a common letter are not significantly different ($\alpha \leq 0.05$)				

Table 2. Patterns of seedling phenology as influenced by population of seed origin.			
Pop	No. of families	Bud stage[z]	Duration of growth [y]
MX-5	4	2.51 a[x]	2.67 b
MX-1	2	1.13 b	2.77 b
TX-1	3	1.17 b	2.09 c
TX-2	2	1.14 b	1.87 cd
MX-4	3	1.12 b	3.71 a
TX-5	5	1.06 b	1.49 d

[z] Bud stage rated on 3/4/96 with scale:
   1=dormant buds, 2=bud swell,
   3=inner scale split, 4=leaf burst, 5=leaf
   expansion.
[y] duration of growth rated on 12/4/96 with
   scale: 1= fully defoliated, 2=>50% leaf
   drop, 3=<50% leaf drop, 4=immature
   leaves or active growth.
[x] Mean separation by paired t test. Ratings
   with a common letter are not significantly
   different (a<0.05)

Table 3. Variation in pecan populations for 1 year old seedling diameter, taproot rank and lateral root rank.

Pop	Dia. (mm)	Taproot rank [z]	Lateral root rank [y]
Nursery	7.07 a	22.17 a	4.55 f
SanFelipe	6.31 b	17.23 b	4.72 f
TomGreen	5.72 c	16.97 bc	6.01 e
Nueces	5.79 c	16.86 bc	6.49 cde
LasMoras	5.63 cd	16.16 bcd	6.61 cd
Devils Riv.	5.52 cd	15.64 cde	6.06 e
Louisiana	5.73 c	15.45 cdef	6.00 e
Brazos	5.85 c	14.95 defg	6.20 de
Scurry	4.85 f	14.24 efgh	7.21 ab
Oklahoma	5.14 ef	14.15 efgh	6.20 de
Champion	5.36 de	13.97 fgh	6.11 de
Alabama	5.79 c	13.81 gh	6.77 bc
Illinois	4.98 f	12.78 h	7.31 a

[z] Taproot rank =maximum root diameter + root diameter at 15 in.
[y] Lateral root rank = Rating for abundance (1 to 3) + rating for diameter (1 to 3) + rating for length (1 to 3).
[x] Mean separation by paired t test. Ratings with a common letter are not significantly different (a<0.05)

Table 4. Variation in seedling diameters (cm), by population, over three years.

Population	n	1996	1997	1998
Nursery	22	2.32 a [z]	3.90 a	6.40 a
Louisiana	13	2.26 a	3.91 a	5.54 ab
Las Moras	10	1.71 ab	3.16 ab	4.76 bc
Alabama	7	1.64 ab	2.64 b	4.32 bcd
Nueces	26	1.59 b	2.72 b	4.74 bc
Tom Green	31	1.49 b	2.55 b	4.33 bc
Brazos	8	1.51 b	2.48 b	4.24 bcd
Champion	11	1.46 b	2.71 b	4.72 bc
San Felipe	14	1.44 b	2.95 b	4.81 bc
Oklahoma	12	1.35 b	2.37 b	3.89 cd
Scurry	27	1.29 b	2.38 b	3.41 de
Devils River	8	1.20 bc	2.37 b	3.73 d
Illinois	3	.46 c	0.66 c	1.06 e

[z] Mean separation by paired t test. Ratings with a common letter are not significantly different (a<0.05)

Table 5. Trunk diameter (cm) of open-pollinated seedstocks of pecan.		
Family	No. of trees	Trunk diameter (cm)
Elliott (Nursery)	6	2.9 a [z]
VC-168 (Nursery)	8	2.6 ab
Louisiana 1	5	2.4 ab
Las Moras 2	4	2.2 abc
Louisiana 3	8	2.1 bcd
Tom Green 3	8	2.0 bcde
Nueces 3	5	2.0 bcde
Scurry 4	7	1.7 cdef
Nueces 4	6	1.7 cdefg
Nueces 1	8	1.7 cdef
Alabama 3	7	1.6 cdefg
Tom Green 4	7	1.6 cdefgh
San Felipe 1	8	1.5 cdefgh
Brazos 4	4	1.5 cdefgh
Burkett (Nursery)	8	1.5 cdefgh
Brazos 2	4	1.5 cdefgh
Oklahoma 1	5	1.5 defgh
Champion 1	7	1.2 fghi
San Felipe 3	6	1.3 efgh
Scurry 3	7	1.3 fghi
Las Moras 4	6	1.3 efgh
Nueces 6	7	1.0 hi
Champion 2	3	1.3 fghi
Tom Green 2	8	1.3 fgh
Devils River 1	8	1.2 fghi
Tom Green 1	8	1.1 ghi
Oklahoma 5	7	1.2 fghi
Scurry 2	6	1.1 fghi
Scurry 1	7	1.0 ghi
Illinois 4	3	0.5 i
[z] Mean separation by paired t test. Ratings with a common letter are not significantly different (a<0.05)		

Table 6. The influence of pollen source on pecan nut parameters						
Tree	Pollen	n	nut length (mm)	nut height (mm)	nut weight (g)	nut buoyancy
EW 7-22	OP	18	34.17 a [z]	29.00 a	7.56 a	2.97 a
	VC-168	17	30.65 b	28.24 ab	7.01 ab	2.05 b
	NC-4	15	31.60 b	28.00 b	6.38 b	2.74 a
EW 7-25	OP	21	41.14 a	28.86 a	8.21 a	3.61 a
	VC-168	6	40.67 ab	26.33 b	8.12 ab	2.64 b
	Pawnee	4	37.50 bc	27.50 ab	7.37 ab	3.06 a
	NC-4	7	36.86 c	27.71 ab	7.13 b	3.23 a
[z]Mean separation by paired t test. Ratings with a common letter are not significantly different (a<0.05)						

Table 7. The influence of pollen source on pecan seedling growth.					
Tree	Pollen	n	Emergence Julian date	height (cm)	diameter (mm)
EW 7-22	OP	13	41.15 b [z]	20.25 a	2.93 a
	VC-168	13	36.93 b	22.07 a	3.17 a
	NC-4	15	52.38 a	15.12 b	2.31 b
EW 7-25	OP	13	38.85 b	21.80 a	3.17 a
	VC-168	6	35.85 b	22.10 a	3.33 a
	Pawnee	3	50.33 ab	17.83 a	2.25 b
	NC-4	1	79.00 a	.	.
[z]Mean separation by paired t test. Ratings with a common letter are not significantly different (a<0.05)					

DISCOVERING THE FUTURE: A NEW PECAN HUSBANDRY PARADIGM?

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Additional index words. Alternate bearing, wisping, hedging, pruning, sunlight, vigor, limb pruning

ABSTRACT

Pecan husbandry is presently driven by management strategies generally accommodating the natural growth habit of native trees--where trees are allowed to grow naturally with farmers striving to manage the consequences. While allowing for successful commercial cultivation, this contributes to many serious problems that presently plague the commercial industry. These problems collectively result in low yield efficiency at both the tree and orchard level and also limit the growth and prosperity of the industry. I present an alternate husbandry potentially allowing for substantially increased orchard yields (and efficiency) while greatly enhancing kernel quality, stabilizing production, and maximizing the use efficiency of orchard space. This paradigm is based on the control of tree size and the establishment of equilibrium between source and sink tissues. It allows for the farmer to rapidly fill allotted orchard space, to annually control tree size, and to largely control alternate bearing. This can be done on large trees by wise employment of selective limb pruning techniques and on small to medium size trees by appropriate annual wisping techniques. I suggest that unless unforeseen events suddenly increase demand for pecan, the future of the industry at the commercial level hinges on a new paradigm conferring greatly enhanced efficiency, and therefore "economic fitness".

The purpose of this report is to introduce a brief discussion exploring the future of the U. S. pecan industry and what researchers and growers might do to prepare for this future. This is done by pointing out an "economic fitness" problem and the suggestion of a possible solution.

The relatively poor "economic fitness" exhibited by the U.S. pecan industry is largely driven by the fact that pecan trees have been managed for generations by orchardists with the mind set of generally letting the tree grow its natural way and become as large as conditions

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allow. This strategy usually encompasses a brief effort in the early stages of tree growth to train a central leader or scaffold limbs. While this strategy lends itself to beautiful orchards and little or no efforts regarding training, it results in major biological and economic challenges which threaten the economic fitness of pecan husbandry. Trees allowed to grow according to their innate natures partition most of their resources into wood to ensure survival as they compete against neighboring trees. This strategy is essential in a riparian, or floodplain, habitat where pecan has evolved and adapted, but is a handicap when a stable supply of high quality kernels are the desired products of husbandry and orchard managers act to insure the tree's survival.

When viewed from the perspective of profitability, which is strongly linked to consistently high production of high quality nut meats, the traditional paradigm commonly practiced today possess three major disadvantages, plus a host of lesser problems. These three are: a) largely uncontrollable disequilibrium between source (foliage) and sink tissues (fruit); b) low intratree yield efficiency; and c) low intertree, or orchard, yield efficiency. This also causes problems with control of pests and nutrient element levels, wind damage, alternate bearing, marketing, etc. Therefore, within the context of profitability or economic fitness, trees allowed to grow naturally will generally insure a continuation of what we experience today. This traditional strategy is similar to the "Wag the Dog" effect (as compared to "Wag the Tail") where a relatively small aspect of husbandry is allowed to control or drive an endeavor.

As pecan scientists we have the opportunity to "Discover the Future" of pecan husbandry. To do so we must anticipate and innovate. The food and tree nut industries are in competition with pecan and are rapidly evolving. Unless there is a major unforeseen event that suddenly and greatly increases demand for food, the pecan industry will surely face considerable evolutionary pressures to improve "economic fitness". The same may also occur without such an event. Failure to enhance "fitness" will likely result in the U. S. pecan industry being slowly relegated to the "endanger species" list and possibly on the "extinct" list. Market forces seem to be such that there are: a) increasing competition for the food dollar; b) greater competition by other nut crops; c) increasing importance of high quality kernels; d) and relatively slow development of domestic and foreign markets. To ensure that the commercial pecan industry continues to prosper it will be important that the industry be anticipatory and innovative. The industry's goal should be "to be at the right place at the right time". To do so it

must find solutions to the problems that are preventing it from possessing this competitive edge.

The existing husbandry paradigm results in peak yield efficiency for trees at age 9-15. Efficiency then declines due to increasing disequilibrium between sink and source tissues. The result is usually enhanced alternate bearing and lower "on year" kernel quality as the tree ages. Kernel quality during "on" years and the degree of annual fluctuations in yield are key measures of the magnitude of the disequilibrium problem. A similar efficiency peak also occurs in orchards insomuch that there is much wasted space in young orchards and much overcrowding in old orchards. There are few, if any, years during the life of orchards where trees are highly productive and orchard space is effectively used. Unfortunately (or fortunately in certain cases), these do not occur simultaneously. Additionally, varieties left to grow as they will, exhibit vastly different yield efficiencies. The challenge to "fitness" is to find a means of keeping individual trees at peak efficiency while also fully occupying orchard space throughout the life of the orchard. This combination obviously possesses great value.

The large trees produced from the traditional paradigm confer several biological problems that limit "fitness". For example, such trees present a canopy that approximates a conglomerate of smaller trees. This results in a great deal of wasted and poorly utilized space that could potentially be highly productive fruiting volume. This composite-like canopy filters out essentially all photosynthetically active radiation by the time the solar beam penetrates ~ 3-6 feet of canopy (depending upon variety), thus light starving most of the vast interior volume of the tree. Additionally, the resistance attributed to hydraulic conductance of water from the roots to the uppermost foliage becomes great enough in tall trees to substantially limit photosynthesis of the upper canopy. Tall trees are also prone to considerable reductions in photosynthesis (and leaf area) due to reduced levels of nutrient elements in the uppermost canopy due to reduced transpirational influx of xylem mobile nutrients. Tall trees also consume a relatively large amount of energy in dark respiration to support woody tissues constructed to allow for gainful competition with its neighbors for light and nutrients.

This traditional paradigm therefore presents an array of problems that appear to be beyond solution or are not economically feasible to solve. Attempts have been made for decades to offer solutions through improved management of nutrient elements, water, disease and insect pests, sunlight, weeds, adjustments in tree spacing, mechanical fruit thinning, etc., but have failed to truly solve the problem. These efforts have not focused on the real cause of low efficiency.

I propose that we are seeing the early phases of the emergence of a new paradigm where economic fitness will be greatly enhanced. While this new paradigm is yet to be born, its prototypes have been emerging for about three decades. The first clear evidence of demonstrated initiative to cast aside the traditional paradigm appears to have been made in New Mexico where the seeds of innovation found fertile soil under the nurturing care of Stahmann Farms, and perhaps other growers as well, who began experimentation with the concept of pruning and wisping to control tree size and alternate bearing to enhance economic fitness. Similar efforts to break with traditional mind sets soon occurred with innovative growers in Georgia, Texas, Arizona, and probably other locations. The vast majority of these efforts were mere "flash in the pan" events that were deemed to be unsatisfactory and therefore resulted abandoned. However, in modified form, such efforts collectively may trigger a revolution in the pecan industry. The ideal spawned in New Mexico was exported to Australia in the 1980's where it found fertile ground in the mind set and innovativeness of Deane Stahmann. His talent for intuitive judgement has probably done more to refine the idea of hedging and wisping than any other single individual. He has developed a system allowing for the consistent production of about 4,200 pounds of high quality in-shell nuts per acre. This is ~50% greater than that of the best orchards in the southwestern U. S. and ~150% greater than those of the southeastern U. S..

It is noteworthy that the two key technical innovations driving the development of a new pecan husbandry paradigm emerged from nontraditional pecan growing regions (New Mexico and Australia)--in environments relatively remote to mind set limitations imposed by tradition. The combined efforts and experience obtained by many innovative growers (such as Deane and Bill Stahmann, Keith Walden, and Paul Leonard,-- to name a few) has now provided us with the knowledge base necessary to refine the concept of maximizing yield efficiency of trees and orchards. Such growers are paradigm pioneers who embraced a new ideal, a new set of rules, at a very early stage and did so in defiance of conventional knowledge. They did not wait until the numbers generated by research presented a convincing story. They exercised great faith in their own intuitive abilities and set about "changing the game rules" which may very well eventually evolve into "changing the game". This means that those unwilling or unable to adapt may eventually find themselves as an evolutionary "dead end".

Information generated by these "paradigm pioneers"

integrated with my own perspectives of tree biology and pecan husbandry tempts me to suggest that the use of an appropriate hedging/wisping strategy is the future of much of the pecan growing regions, especially that of arid environments. Its future in humid environments is uncertain. This is primarily because of pecan scab disease. A fundamental question is whether the succulent growth generated by annual wisping will be compatible with pecan scab. Fortunately another technological advancement, the tangential fan sprayer with controlled droplet size technology , appears to offer great potential for improving coverage of canopy to allow for control of the disease. Recent advances in weather based spray strategies and timing of applications also enhance the feasibility of effecting a paradigm shift in the humid southeastern U. S.

There is not likely to be any one single hedging/wisping strategy will be best, especially since soil, variety, tree size, and tree spacing are major factors that potentially influence the final strategy. However, in general, the strategies that presently appears to be especially promising are as follows:

In planned, yet to be established, orchards: Choice of varieties will differ depending upon location, but in general 'Wichita', 'Apache', "Cape Fear', 'Shoshoni', 'Tejas', probably 'Navaho', and possibly 'Pawnee' appear to exhibit greatest potential. Trees should be established on the best soil available and planted in rows aligned N-S. The spacing should be ~ 15 ft. within the row and ~30 ft between rows. Trees should be left to grow normally during the first few years except for removal of limbs impeding upon future harvesting and herbicide applications. Trees should be grown to produce hedgerows by beginning hedging operations once tree limbs extend to about 8 ft from the trunk. Since pruning dwarfs trees, the less pruning probably the better, except for absolutely necessary training. Trees should be hedged back to about 4-5 feet on each side, resulting in a 8-10 "after hedging" canopy that will extend to 12-14 feet "after regrowth". This hedging is done on the eastern and western faces with trees allowed to grow in height until they are eventually topped and held at about 35 ft. This side hedging is done at a 5-degree angle to allow for a narrower top than base to facilitate light penetration. Repeated hedging, or wisping, is done each year thereafter to hold trees to their allotted space and to ensure equilibrium between sink and source tissues. This strategy will result in a minimal amount of wasted fruiting volume per tree and per orchard. Unknowns that need to be considered concerning this approach are: a) role of summer pruning of vegetative growth on the sides or tops of the trees to facilitate sunlight penetration to the interior of the hedge; b) the optimal ratio of hedgerow height to row width; c) the tree size to

begin hedging; d) flat top or roof top topping; e) whether topping needs to be performed every year; and f) long-term influence of disease and insect pests on tree longevity as a result of wounding.

In existing orchards with small to moderate size trees. Existing orchards offer special challenges insomuch that intertree spacing and possibly orientation are no longer controllable (unless new trees are planted "in between" existing trees). Tree size also presents additional challenges. Anecdotal evidence suggest that in general, assuming trees are on a more or less square or diamond planting, trees should be pruned by whatever manner feasible to produce a skeletal structure extending about 1/3 (minus 2 feet) of the distance from the trunk of the tree to the adjoining row. Thus if row spacing is 40 feet then the tree should be shaped to ~11.3 feet from the trunk. Such trees therefore produce discrete canopies (vs. hedgerows). Repeated wisping should be on a 2-year cycle with opposite faces being done at each cutting with cuts being made at about 13 feet from the trunk. The top should be roof-topped when the side-cuts are made. Sides should be sloped at 5 degrees. An alternative is to hedge on a 4-year cycle with opposite sides being hedged at each 2-year cutting. This strategy is also suitable for large trees if they are first dehorned to conform to the limitations of the hedging machine.

In existing orchards with relatively large trees. A viable alternative to hedging and wisping appears to be that of selective heading back of certain scaffold limbs on an annual basis. The "paradigm pioneer" for this approach is Ray Worley of the University of Georgia and Joe Mitchell of Tombstone, Arizona. Large trees display a rather impressive array of primary and secondary limbs that are absent of foliage or fruiting points for 2/3 - 4/5 of their length. This causes great wastage of potential fruiting volume within the tree's canopy. The pioneering approach of Ray Worley was modified by the intuitive insight of Joe Mitchell insomuch that it was recognized that such trees need to be invigorated and to receive high levels of interior sunlight to existing supportive structures. This strategy was brought to my attention by Mike Kilby who readily recognized its potential. This strategy is to head back annually 1 or 2 major limbs by about 1/3 - 1/2 of their length. This is done being careful to avoid cutting in crotches since such cuts fail to induce the degree of vigor and fruiting response observed when cuts are made between crotches. The result is that such cuts, especially when initially localized in the upper interior of the tree, greatly improve the level of sunlight penetration into the interior of the canopy. This increased sunlight triggers the development of a multitude of dormant adventicious buds within the blind zone of the scaffold limb, resulting in a tremendous

regrowth of shoots along the previously blind scaffold zone if the tree has been well watered and maintained. The shoots are highly fruitful the following year. This approach ensures that the tree is invigorated annually, is reduced in size, and approaches equilibrium between sink and source tissues. A "blind eye" (i.e., limbs selected almost at random) should allow the grower to substantially enhance the tree's yield efficiency, whereas a "keen eye" (carefully selected limbs) used in the selection process should produce truly remarkable results. The decision to "head" is made on a tree by tree basis and my not be an annual event, especially after 3-4 years of heading.

Both of the above described strategies can be used to ensure that intratree and intertree (orchard) yield efficiencies are greatly improved and become near optimum and that trees are maintained at or near equilibrium between sink and source tissues (although it will not necessarily totally eliminate alternate bearing it will be greatly minimized). This new paradigm also confers many additional advantages concerning leaf efficiency, nutrient disorders, pest control, wind damage, tree replacement, etc. This system allows the grower the option of rapidly filling allotted space with fruiting volume that produces high quality nut meats while also likely meeting the "economic fitness" demands of the future. Thus, the grower has evolved from the "Wag the Dog" approach of the traditional husbandry paradigm to the "Wag the Tail" approach of an emerging paradigm. This new paradigm operates under a new set of rules and is in effect an new game. Changing these rules has the potential for changing the world of pecan. As the new paradigm becomes increasingly accepted, it will be discovered that just about everything currently practiced in pecan culture will need to be reexamined for merit, thus giving pecan scientists plenty to do.

A new paradigm appears to be in the birth process; however its final form, or nature, is yet to be determined. Market realities and innovative growers guarantee its birth and continued evolution. As a new paradigm it puts everyone practicing the old traditional paradigm at risk. This includes growers and scientists alike. This presents a special challenge because the better we are at our existing paradigm, the more we have invested in it, and the more we have to lose by changing paradigms (or the rules, or the game). The conversion process will be slow with the most reluctant being the biggest losers in the end. As pecan scientists we have a special opportunity to assist in the maturation of this paradigm, therefore making what may become a revolutionary contribution to the enhancement of the economic fitness of the U. S. pecan industry.

WATER QUALITY GUIDELINES FOR OPTIMUM PRODUCTION OF SURFACE-IRRIGATED PECANS: SALINITY AND SODICITY

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Additional index words. Salt tolerance, water infiltration, salt leaching.

ABSTRACT

Quality of water used for growing pecans, especially salinity has been a concern of irrigated pecan growers. This study was conducted for developing tentative salinity and sodicity guidelines necessary for sustaining irrigated production of pecans at or near optimum in a broad range of soil textural classes. The approach used is based on the assumption that salt and sodium accumulation in orchard soils is controlled by hydraulic properties of the soils, besides the quantity and quality of water applied. The following factors were considered in developing the guidelines; i) salt and sodium tolerance of pecans, ii) sodicity effects on water infiltration and salt leaching, and iii) salt and sodium accumulation potentials in different soil textural classes. Results indicate that the target soil salinity limit for growing pecans at or near optimum is probably around 1.5 dS m^{-1} in the saturation extract, but it can be increased until Na concentrations in the saturation extract reach approximately 230 mg L^{-1}. The target soil sodicity limits not to induce water infiltration and salt leaching problems may range from 4 to 6 in structurally weak alluvial silty clay loam, 7 to 11 in silty clay loam developed in upland, and 7 to 10 in alluvial loam, all expressed in the sodium adsorption ratio of the saturation extract. The level of salt accumulation in the root zone observed in the El Paso valley was dependent of the saturation water content, and ranged from 0.8 to 1.2 in loam, 1.2 to 2.0 in silty clay loam, and 2 to 4 in silty clay in salt concentration ratios computed as the salinity of the saturation extract divided by that of irrigation water. Salinity guidelines of irrigation water for growing pecans may be set by dividing the target soil salinity or Na concentration by the applicable salt concentration ratios, and the guidelines for sodicity based on the sodicity limit necessary for leaching salts and sodium during preseason irrigation. Future appraisal of water quality for growing pecans can be made preferably by measuring sorptivity of field soils.

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INTRODUCTION

Quality of water used for irrigation, especially salinity has been a concern of irrigated pecan growers in the Southwest and the northern states of Mexico. Pecans are known to be salt-sensitive (Miyamoto et al., 1989). Sodicity is also a concern, because of its deteriorous effect on soil structure, water infiltration, and drainage, especially in clayey soils. Also, there has been some concern over chloride (Cl) which causes leaf burns, and the toxic effects of boron (Faruque, 1968; Picchioni, et al., 1991). Fortunately, the occurrence of Cl and B problems has been rather limited in the Southwest. The most frequently asked question is the concentration of salts and sodium in irrigation water, which is suitable for producing pecans at or near optimum on a sustainable basis. To answer this question, it is necessary to have the information on salt and sodium tolerance of pecans, and soil responses to sodicity. The first objective of this study was to review or acquire these baseline data. The second objective was to examine ways to assess salt and sodium accumulation potentials in surface- irrigated soils. Upon these considerations, tentative water quality guidelines for salinity and sodicity are suggested for sustainable irrigated production of pecans in the Southwest.

BASELINE DATA

Salt and Sodium Tolerance: Seedling growth responses to salinity, Na and Cl concentrations were previously studied through a 2 year outdoor lysimeter experiment involving "Apache", "Burkett" and "Riverside" (Miyamoto et al., 1985). According to this study, seedling growth of all cultivars tested began to decline as soon as salinity of the soil solutions exceeded 2.4 dS m^{-1} or salinity of the saturation extract exceeded 1.6 dS m^{-1} (Fig. 1). This relationship was observed when the molar ratio of Na, Ca and Cl was kept at 3.8 :1:2 in the irrigation solutions, simulating a typical composition of the Rio Grande water. When the chloride concentration was increased from 525 to 1065 mg L^{-1} (or 14.8 to 30 mmol L^{-1}) in the irrigation water, no additional significant growth reduction observed. However, when Na concentrations were increased from 610 to 810 mg L^{-1}, while maintaining the same salinity level, substantial growth reductions occurred. When the growth data were plotted against the Na concentration in soil solutions, the relationship became linear with a high degree of correlation (Fig. 2). An addition of CaSO$_4$ to raise the salinity by 0.9 dS m^{-1} did not cause an additional growth reduction. These findings may suggest that seedling growth observed may have been controlled principally by Na concentrations in soil solutions, rather than by salinity (or the osmotic effect).

Field observations of tree growth and soil salinity relationships were previously reported by Miyamoto et al. (1985), using 14 to 18 year old "Western". Soil samples were taken from 0-60 cm, and were analyzed for salinity and Na concentrations in the saturation extract. According to the observations (Fig. 3), the cross-sectional area of tree trunk decreased linearly toward the intercept salinity of about 9 dS m^{-1} or the Na concentration of 68 mmol L^{-1} (1560 ppm) at the intercept where tree growth presumably becomes zero. These observations made with maturing trees seem to coincide with the seedling growth data shown earlier in Fig. 2.

Field observations of nut yield responses to salinity and Na concentrations were previously reported by Miyamoto et al. (1986) for 11 years old "Western". In the experiment, soil salinity of the top 60 cm was increased to 4.2 dS m^{-1} in the saturation extract, while soil salinity of the control plot was kept at 2.2 dS m^{-1} for 4 years. The corresponding Na concentrations in the saturation extract were 760 and 370 mg L^{-1}, respectively. Nut yields in the high salt plot were reduced by 44% during on-years, and 71% during off-years. Another field observation recently made in Tornillo, TX (unpublished), using 27 years old "Western" with an average trunk diameter of 30 cm has shown a significant yield reduction as soil salinity of the top 60 cm exceeded 1.3 dS m^{-1} (Fig. 4). Nut yield reduction during off-year is not available, but based on the results of the control experiment mentioned earlier, it is probably greater than on-year reductions.

The seasonal differences in salt tolerance are unknown at present. However, a field report of Miyamoto et al. (1986) indicates that salt stress during the early season is likely to reduce shoot growth, and leaf development. This may suggest that salt (or sodium) stress can be quite damaging to young trees which require rapid tree growth. The same report also indicates that salt (or sodium) stress caused a significant reduction in leaf area during both on and off-years, and a significant reduction in nut sizes and fillings only during on-years when soil salinity was increased from 2.2 to 4.2 dS m^{-1} in the top 60 cm. Reduced leaf area can lead to a reduction in photosynthesis. A separate observation indicates that salt stress up to 3.6 dS m^{-1} did not cause nut quality degradation during an on-year, although the yield was reduced by 27% (Fig. 4).

These reports seem to indicate that soil salinity should be kept below about 1.5 dS m^{-1} for optimum tree growth, but it can be increased until Na concentrations in the saturation extract reach about 230 mg L^{-1} (or 10 mmol L^{-1}). The optimum soil salinity or Na concentrations for nut yield attainment could be higher in mature trees, but probably not substantially.

Sodium Effects on Soils: It is widely recognized that high soil sodicity can adversely affect soil structural stability, soil hardness, shrinkage and swelling (e.g., Emerson, 1984) as well as water infiltration (e.g., Shainberg and Letey, 1984). The effect of sodicity on water infiltration is especially critical, as it affects salt leaching as well as irrigation efficiency and management. In spite of the wide-spread awareness of sodium effects on soils, there is a great deal of uncertainty as to its effect on the soils used for pecan production in the Southwest. Therefore, water infiltration experiments were recently conducted to evaluate the extent of sodicity effects. Soil samples were collected from the El Paso Valley and from the Pecos area, and were conditioned to have exchangeable Na percentages of 1, 12, 25 and 50. The dry soil samples were packed into infiltration columns to a depth of 60 cm at a bulk density comparable to that of field soils. Water infiltration was measured for a period of one month under continuous ponding of irrigation solutions having the same SAR values as those of the soils at two levels of salinity (700 and 1700 mg L^{-1}). From these infiltration data, the sorptivity (defined by the following equation) was then determined.

$$D = S \, t^{1/2} \qquad (1)$$

where D is the cumulative depth of water infiltration, t is the duration of ponding, and S the sorptivity determined from the slope of the plots D vs $t^{1/2}$. The sorptivity value is equal to the cumulative infiltration when t is unity, such as one day. The sorptivity determined is shown in Fig. 5 as a function of SAR of irrigation solutions. Note that the sorptivity of Harkey loam did not decrease greatly at a SAR of 12, whereas the sorptivity of both Saneli and Hoban silty clay loam decreased sharply at the level of SAR or higher.

The sorptivity equation (Eq. 1) is applicable during the initial phase of water infiltration, usually less than 20 to 30 cm in cumulative infiltration depth. Thereafter, the rate of water infiltration approaches more or less constant values, commonly referred to as the steady-state infiltration rate or permeability. These values were determined from the later phase of the infiltration process, and are plotted as a function of SAR of the water used (Fig. 6). The data shown indicate that permeability is even more dependent on SAR than the sorptivity, and this can be attributed to a greater degree of soil structural degradation over time.

Once preseason irrigation is completed, the primary concern of growers is to attain water infiltration to refill

the soil water depletion, preferably under water ponding not to exceed a few days. An additional soil column experiment was then conducted to observe the effects of sodicity on infiltration of water under repeated irrigations, as practiced in crop irrigation. Soil samples were packed into infiltration columns at bulk densities comparable to field soils. The first three irrigations were made using water sources having various levels of sodicity, and the 4th irrigation with the Rio Grande water in all soil columns, using 10 cm per application.

The infiltration depth was not affected significantly by water quality during the first irrigation, but became apparent during the subsequent irrigations, especially during the 4th irrigation when the Rio Grande water with comparatively low salinity (700 mg L^{-1}) was used in all columns (Fig. 7). The depth of water infiltration relative to that obtained under Na free conditions ($CaCl_2$ treatment) was then computed when the reference infiltration reached 10 cm, and is shown as a function of SAR of different water sources used for the first three irrigations (Fig. 8). The infiltration depth of two alluvial soils from the El Paso Valley (Saneli and Harkey) decreased with increasing SAR more so than Hoban soil. Glendale silty clay is also an alluvial soil, but was least affected. This soil has the strong tendency of swelling and shrinking, which may have helped water infiltration. The differences in infiltration depth were somewhat reduced during the next irrigation with the different water sources having higher salinity levels.

Overall, sodicity effects observed during the second experiment simulating crop irrigation under surface methods were not as pronounced as those on sorptivity or permeability shown earlier in Figs. 5 and 6. If the second experiment were continued for a longer period, however, the differences in infiltration depths would have been magnified. In addition, soil structural developments induced by periodic drying of the soils and lower SAR of the soil surface than those indicated in Fig. 8 (which is caused by Na leaching when the Rio Grande water low in SAR was applied) can account for the apparent differences. Water infiltration responses will be greater if irrigation water sources with lower salinity than the tested concentration of 700 mg L^{-1} are used.

APPRAISING SALTS ACCUMULATION

Salinity: The most uncertain aspect of irrigation water quality appraisal is the difficulties involved in predicting the level of salt and sodium accumulation in diverse soils. The conventional method assumes that the steady-state salt balance is controlled by the quantities of water applied relative to the evapotranspirational losses of water (e.g., USSL, 1954).

$$C_D = C_I \, D_I/D_D = C_I D_I/(D_I - ET) \qquad (2)$$

where **C** and **D** denote, respectively, the concentration of dissolved salts, and the depth of water, with subscripts **I** and **D** designating irrigation and drainage water, respectively, **ET** designates the evapotranspiration. The inverse of the term D_I/D_D is commonly referred to as the leaching fraction (**LF**).

$$LF = D_D/D_I = (D_I - ET)/D_I \qquad (3)$$

These equations have been tested satisfactorily over the years, but at times, leading to the notion that salts will be leached if we apply water in excess of **ET**. Such an assumption is valid only if the soil is sufficiently permeable. In clayey soils with inherently low permeability, the water applied may or may not adequately drain through the soil profile. Reduced water penetration is accompanied by increased evaporation from the soil surface, and by salt accumulation in soils. In other words, the leaching fraction is soil-dependent, as much as the quantities of water applied.

An alternative approach suggested is based on the assumption that the levels of salt accumulation in the root zone can be defined by using the salt concentration ratio (**SCR**), and that the **SCR** can be correlated to certain soil properties. The **SCR** is simply calculated as

$$SCR = C_e/C_I \qquad (4)$$

where C_e is the salinity of the soil saturation extract, and C_I the salinity of irrigation water.

The salt concentration ratios determined at several pecan orchards in the middle Rio Grande Basin (Miyamoto and Cruz, 1986) were then plotted against the saturation water content, or more precisely the water content of the saturated paste used for soil salinity analysis (Fig. 9). The saturation water content (**SWC**) is an indication of soil texture, although high soil sodicity can affect its determination to some extent. The **SCR** in sandy or loamy soils can be less than 1.0, because of dilution with distilled water during soil testing. The significant correlation observed between **SCR** and **SWC** (Fig. 9) may indicate that the regression equation can be used to estimate the levels of salt accumulation in different soil textural classes when water of given salinity is used for irrigation. In upland soils with better drainage, the **SCR** could be lower than those shown at a given **SWC**. The advantage of this method is its simplicity. However, this regression approach can not account for the effects of sodicity or soil management measures used to change hydraulic properties of soils

within or across soil textural classes.

Sodicity: The appraisal of soil sodification potential has traditionally been made by the following equation (e.g. Rhoades, 1968).

$$SAR_D = (D_I / D_D)^{1/2} SAR = (LF)^{-1/2} SAR \qquad (5)$$

where SAR_D is the sodium adsorption ratio of drainage water below the root zone. As indicated earlier, it is not reliable to estimate D_I/D_D or LF from irrigation data alone in clayey soils.

An alternative approach suggested here utilizes the salt concentration ratio (SCR)

$$SAR_e = [(SWC/FSM) SCR]^{1/2} SAR \qquad (6)$$

where SAR_e is the sodium adsorption ratio of the saturation extract, **SWC** the saturation water content, and **FSM** the field soil moisture content during or shortly after irrigation. In well-drained soils, **FSM** is close to what is commonly referred to as field capacity. In alluvial soils with high water tables or with abrupt stratification, **FSM** of subsoil is usually closer to the saturation water content.

Eq (6) can be used to estimate soil sodicity from **SAR** of irrigation water if **SCR** is known. The relation between SAR_e and **SCR** of the root zone samples collected from the El Paso Valley are shown on Fig. 10, where **SAR** of irrigation water was measured to be 5.4. Included in the figure is the theoretical curve given by Eq (6) where **SWC/FSM** was assumed to be 1.0. The observed values were distributed along the theoretical line when **SCR** was less than 2, then deviated somewhat from the predicted, partly due to the presence of gypsum in the soils with poor drainage. Nonetheless, Eq (6) can be used to estimate soil sodicity, at least as the first approximation.

Sorptivity Based: The methods discussed above are essentially based on regression, and can not account for various factors which affect hydraulic properties and salt accumulation in soils. This includes the difficulties of isolating sodicity effects on salt accumulation. A potentially effective method of assessing both salts and sodium accumulation in irrigated soils involves the use of sorptivity, coupled with an appropriate salt and sodium transport model. Such a method is mentioned here as a possibility as well as to show that infiltration characteristics discussed earlier are closely tied with the salt balances in field soils. This approach incorporates the fact that the best time, and perhaps the only time, to

leach salts from irrigated clayey soils is during preseason irrigation when the soil is most permeable. In other words, the sorptivity mentioned earlier becomes an important parameter of assessing salt leaching potential. To illustrate this point, the depth of water infiltration and penetration in Harkey loam and Glendale silty clay loam (similar to Saneli silty clay loam) was calculated using the data shown in Fig. 5. The irrigation water used had salinity of 1.23 dS m^{-1} and a SAR of 5.4, and was assumed to be ponded for 2 days. The depth of water infiltration was estimated to be 27 and 18 cm from the sorptivity data, and the depth of penetration 110 and 60 cm in Harkey loam and Glendale silty clay loam, respectively. The observed salt distribution patterns, which are examples of several field observations, were consistent with the estimated penetration depths. Other examples came from alfalfa fields, both consisting of Harkey loam. The first one has been irrigated with water similar to the one mentioned above, and the second using sewage effluent with an SAR of 12 and salinity of 1.6 dS m^{-1} during winter months when the project water supply is curtailed. The sodicity of the soil surface was reportedly increased to 18 in SAR_e. The depth of water infiltration for one-day ponding as practiced in this field was estimated to be 14 cm at a SAR of 18 (Fig. 5), and the depth of penetration no more than 58 cm. This seems to be the case where high sodicity induced the water infiltration problem, then was followed by salt accumulation, which then further elevated soil sodicity. Although the data currently available do not permit further analyses, these examples may indicate the potential advantage of this approach for appraising salt and sodium accumulation potentials.

SUGGESTED GUIDELINES

Salinity: The target soil salinity limit for growing pecans at or near optimum appears to be around 1.5 dS m^{-1}, but it can be increased until Na concentrations reach approximately 230 mg L^{-1} (or 10 mmol L^{-1}) in the saturation extract. This Na concentration limit is to avoid specific Na Effects, and actual Na concentrations may have to be lowered to meet the sodicity limits discussed later. Soil samples are assumed to be taken from the most active root zone which is typically the top 60 cm. In the case of gypseous soils (the soils containing gypsum), the salinity limit can be extended as shown by the high salinity value in Table 1.

The water quality guidelines to meet the above targets can be determined simply by dividing the target limits by the salt concentration ratios (SCR) applicable to the soil textural classes in question. The typical ranges of SCR observed in alluvial soils of the Rio Grande (Fig.

9) are summarized in Table 1. For upland soils with stable soil structure and better drainage, the **SCR** values can be somewhat lower. At the same time, the **SCR** can increase when the soils become compacted or affected by sodium. Soil and irrigation management is a factor which affects **SCR**, but usually not as much as soil texture or inherent soil permeability. In gypseous water with low Na concentrations, the salinity limit of irrigation water can be extended, possibly to as high as 3.0 dS m^{-1} in loam or sandy soils, provided that gypsum precipitation in subsoils does not restrict drainage. In clayey soils, however, both salinity and Na concentration limits must be set low as shown in the last two rows of the table.

The salinity guideline presented utilizes salinity of the soil saturation extract, a parameter most commonly used by practicing soil scientists. This parameter is not the most accurate measure of expressing salt effects on crop performance, and future studies may incorporate the mean soil solution salinity of the major root zone for improved accuracy.

Sodicity: The target soil sodicity limits depend on soil properties and soil management concerns. As indicated earlier, the best time to leach salts and sodium from clayey soils is during preseason irrigation. The quantities of water applied vary, but generally no more than 8 inches (20 cm) per application with the border-setting equipment ordinarily used. Irrigation at this depth usually saturates the soil to the depth of the main root zone, then penetrates into subsoils during redistribution. To avoid complication in orchard management and adverse effects on trees, it is desirable to complete preirrigation within several days. The sorptivity necessary to achieve the 20 cm infiltration in 2 and 3 days is 14.1 and 11.5 cm day$^{-1/2}$, respectively. The SAR levels necessary to allow the degree of water infiltration can be determined from the sorptivity data shown in Fig. 5. In structurally weak Saneli silty clay loam, the soil sodicity, which permits the necessary levels of sorptivity, ranges from 4 to 6, and 7 to 11 in structurally stable upland silty clay loam, when water containing 700 mg L^{-1} of dissolved salts is assumed to be used for preirrigation. The sorptivity necessary for the 20 cm infiltration in 2 days instead of 3 days is listed in Table 1 as a guideline. In Harkey loam, the sorptivity remained high even at a **SAR** of 12 (Fig. 5), but under field conditions, it is most likely that soil structure will disintegrate under repeated irrigations, thus leading to lower sorptivity. The guidelines were suggested by assuming that the sorptivity may eventually decline into a pattern conforming to other soils. The sodicity limit for silty clay is an estimate only. No **SCR** correction was incorporated as frequent irrigation made during summer and fall months generally leach out the salts from the soil surface. The flow-limiting layer under ponded leaching is the surface layer, usually not exceeding 12 cm in depth (Miyamoto and Enriquez, 1989), unless there is a marked soil textural change with depth.

The soil sodicity limits for crop irrigation were determined with the following considerations. First, irrigation water applied in quantities slightly exceeding soil water depletion should infiltrate in less than 2 to 3 days so as to avoid aeration problems. This requirement appears to be met even when irrigation is initiated at low soil water depletion if sodicity of irrigation water does not exceed about 10, even in structurally weak soils such as Saneli silty clay loam (Fig. 7). This, of course, assumes that soil compaction problems are taken care of. Second, sodicity should be kept below a level that the salt concentration ratio (**SCR**) of the root zone would not exceed the desired limits. To examine this requirement, the salt concentration ratio was assumed to be inversely related to the depth of water infiltration.

$$SCR = SCR_O \, (D_{IO}/D_I) \qquad (7)$$

where SCR_O is the salt concentration ratio at **SAR** = 0, D_I the depth of water infiltration, and D_{IO} the depth of infiltration at **SAR** = 0.

According to Fig. 8, D_I/D_{IO} is a function of **SAR**, and is soil-dependent. The **SCR** shown in Table 1 was obtained when the **SAR** of irrigation water used was 5.4. Based on these data, SCR_O was estimated to average 0.89, 1.33, and 2.85 for loam, silty clay loam, and silty clay, respectively. When irrigation water with salinity of 1 dS m^{-1} is to be used for irrigation (comparable to salinity of water used to develop the information shown in Fig. 8), the **SCR** required to satisfy the target soil solution salinity of 1.5 dS m^{-1} is 1.5. This means that the target **SCR** can not be attained by lowering **SAR** in silty clay. In silty clay loam, the target **SCR** can be attained if the **SAR** of irrigation water is close to zero, but this is not a realistic expectation. This means that water of lower salinity has to be used for irrigation, or salt and sodium leaching has to be made during preirrigation. Therefore, the sodicity targets used for preirrigation were adopted as the guidelines with one minor modification involving the upper limit of **SAR** in loamy soils. This limit of 10 was placed based on field observations that the use of water with a **SAR** of 12 caused salt accumulation even in loamy soils (Fig. 12). The projected **SCR** was estimated by reading D_I/D_{IO} values for the specified **SAR** (Fig. 8), then applying Eq (7). These values are shown in the second column from the last with the heading of "Projected SCR, Rootzone" in Table 1.

If water of the specified **SAR** is used for crop irrigation, an additional concern is sodium accumulation in subsoils. This problem was first examined by estimating the salt concentration ratio of subsoils from the projected **SCR** of the root zone by using the following equation. (This arithmetic is not required if the **SCR** of subsoils is known).

$$SCR = (FSM/SWC)(a\, C_I + C_D)/C_I(a + 1) \quad (8)$$

or $$C_D/C_I = (SWC/FSM)(a + 1)\, SCR - a \quad (9)$$

where a is a proportional factor to equate the mean salinity of the root zone with salinity of irrigation and drainage water (Rhodes, 1974), and is 2 to 3 for loam, and 1.5 to 1.0 for silty clay loam and silty clay, respectively, provided that no abrupt stratification occurs within the root zone or immediately below. The term **SWC/FSM** is used to convert the concentration in the saturation extract to that of soil solutions. The product of C_D/C_I and **FSM/SWC** is the salt concentration ratio of subsoils, and C_I/C_D is equal to the leaching fraction. These equations are applicable when **SCR** is greater than 1.0. The projected salt concentration ratio of subsoil is given in the last column of Table 1 under the heading of "Projected SCR, Subsoils". The projected **SAR** of drainage water was then calculated by Eq (6), and is listed in Table 1 (with a footnote designated as 5) when **FMC/SWC** was assumed to be 0.5 and 1.0.

The estimated leaching fraction in silty clay loam, assuming **FWC/SWC** to be 0.5 is 18 to 20%, and in silty clay 9 to 10%. This means that the rate of drainage during the summer months (when the **ET** may average 1 cm per day) would be around 0.2 cm/day in silty clay loam, and 0.1 cm/day in silty clay. The estimated levels of subsoil sodicity are below the levels which may impose significant restrictions in drainage at the estimate rates (Fig. 6). However, if water of higher sodicity than the specified is used for irrigation, or the drainage was limited due to inadequate irrigation or other reasons, subsoil sodicity can become a concern, especially during preseason irrigation when higher rates of drainage are required. Likewise, subsoil sodicity may become flow-limiting when the soil profile contains poorly permeable subsoil such as a clay pan, or a high water table.

One additional concern is the precipitation of calcium carbonate and gypsum in soils when irrigation water used is high in Ca, HCO_3 and/or SO_4. The presence of gypsum is beneficial in terms of lowering soil sodicity. However, the excess can precipitate in pore spaces of subsoils at low leaching fractions and can cause a reduction in subsoil permeability. There is some evidence to indicate that this is taking place in clayey soils with poor drainage. If an orchard is located in the area of gypseous water, subsoil conditions should be examined. There are several computer models to estimate the extent of gypsum precipitation, but it is difficult to predict its effect on subsoil drainage. Preseason irrigation after subsoiling is probably the most cost-effective method of minimizing pore plugging with precipitated gypsum.

These tentative guidelines are based on the prevailing soil conditions and management practices used in the El Paso Valley, and relying heavily on the observed relationship between the salt concentration ratio and the saturation water content (Fig. 9), and the laboratory determined infiltration responses to sodicity (Fig. 5). When these guidelines are to be used in areas with different soils and management practices, these two crucial data sets should be verified. For future attempts to develop water quality guidelines, the sorptivity-based approach may prove more effective, especially when the parameter is determined under field conditions. Such an approach can be combined with salt transport models for assessing salt and sodium leaching potential.

ACKNOWLEDGMENT

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Table 1. Tentative salinity and sodicity guidelines for growing pecans in different soil textural classes under surface irrigation in the Southwest.

Soil Tex. Classes[1]	Salinity	Sodium Concentration	Sodicity (SAR)		
			Leaching	Crop Irrig.	Drainage
	dS m^{-1}	mg L^{-1}	---------------(meg/L)^{½}-----------------		
Target Limits in the Soil Saturation Extract					Projected
I[1]	1.5 - 2.3[2]	<230[3]	>7[4]	7 - 10[4]	7 - 17[5]
II	1.5 - 2.3	<230	4 - 7	4 - 7	6 - 16
III	1.5 - 2.3	<230	<4	<4	7 - 13

Typical Salt Concentration Ratios (Root zone)		Projected SCR at the above SAR values			
	Observed	Estimated for Na		Root zone	Subsoils
I[1]	0.8 - 1.2	0.8 - 1.2	-	1.0 - 1.1	1.0 - 1.4
II	1.2 - 2.0	1.2 - 2.0	-	1.6 - 1.7	2.5 - 2.7
III	2.0 - 4.0	2.0 - 4.0	-	3.0 - 3.1	5.0 - 5.2

The Upper Limits of Salinity, Na concentrations, and Sodicity of Irrigation water for Optimum Production

Soil Tex. Classes	Salinity	Sodium Concentration	Leaching	Crop Irrig.	
I[1]	1.3 - 2.9[2]	190 - 280[3]	>7[4]	7 - 10[4]	
II	0.8 - 1.9	115 - 190	4 - 7	4 - 7	
III	0.4 - 1.2	57 - 115	<4	<4	

[1] Soil textural classes characterized by the saturation water content expressed in ml/100g

I	30-45	includes loam, and silty loam
II	45-60	includes silty clay loam, and clay loam
III	60-90	includes silty clay, and clay

[2] The high values may apply to soils containing gypsum or to irrigation water high in Ca and SO$_4$, but low in Na.

[3] These Na levels are to avoid specific Na affects, and in the case of irrigation water quality appraisal, these values must be lowered to meet the sodicity and salinity limits. Typically, the upper limits of Na concentrations in irrigation water which meet these limits in structurally weak alluvial soils are closer to the low range of the suggested values in the last three rows of the table.

[4] These sodicity values are suggested with an assumption that salt leaching will be accomplished during preirrigation. The lower values may apply to structurally weak alluvial soils, and the higher values for structurally stable upland soils.

[5] These values are estimated sodicity in subsoils when irrigation water with the specified sodicity is assumed to be used for irrigation.
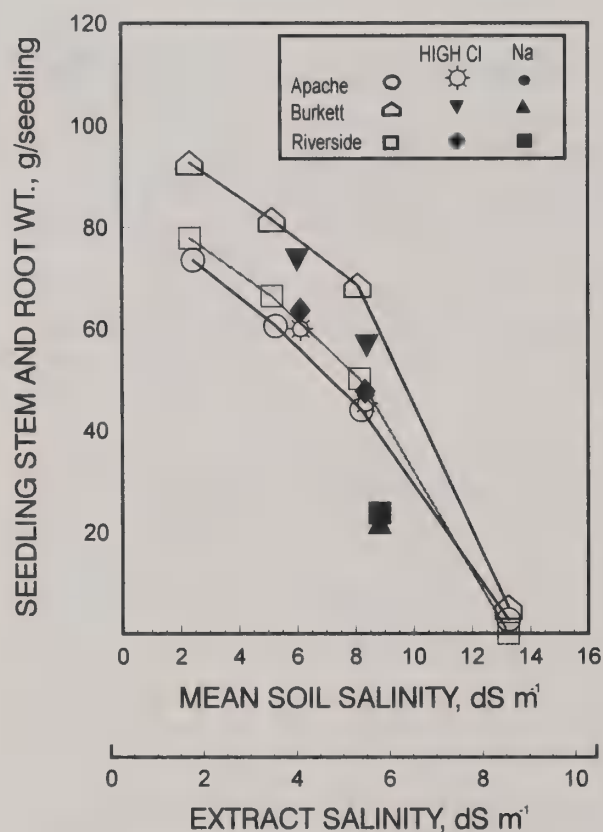
Fig. 1. Growth of pecan rootstock seedlings as related to mean salinity of the soil solutions or salinity of the saturation extract (Miyamoto et al., 1985).
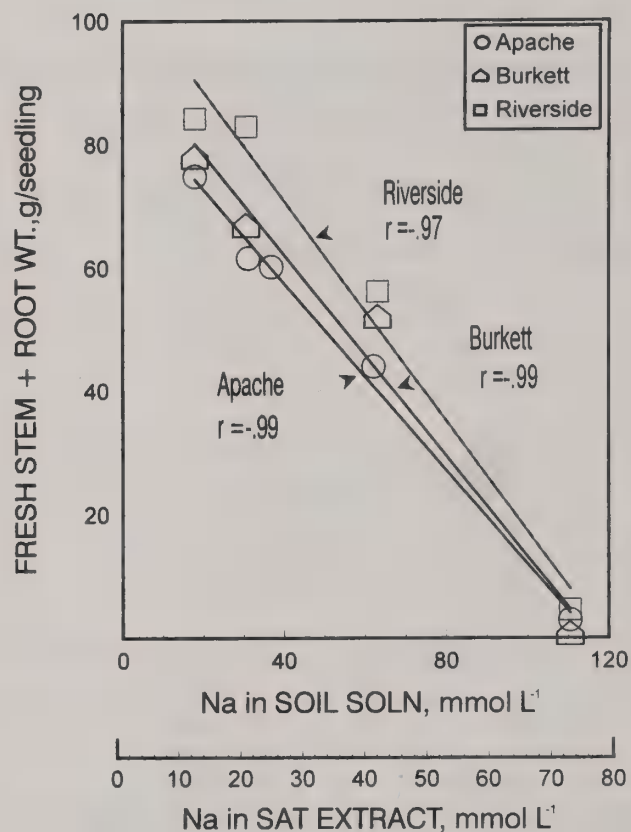
Fig. 2. Growth of pecan rootstock seedlings as related to Na concentrations in the soil solutions or in the saturation extract (Miyamoto et al., 1985).
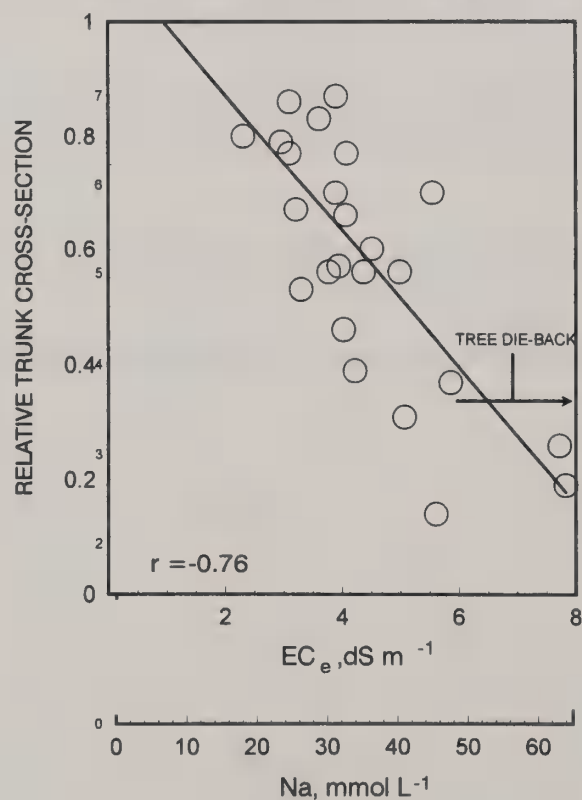
Fig. 3. Trunk cross-sectional areas of "Western" as related to salinity or Na concentrations in the saturation extract in a soil depth of 0 - 60 cm (Miyamoto, 1989).
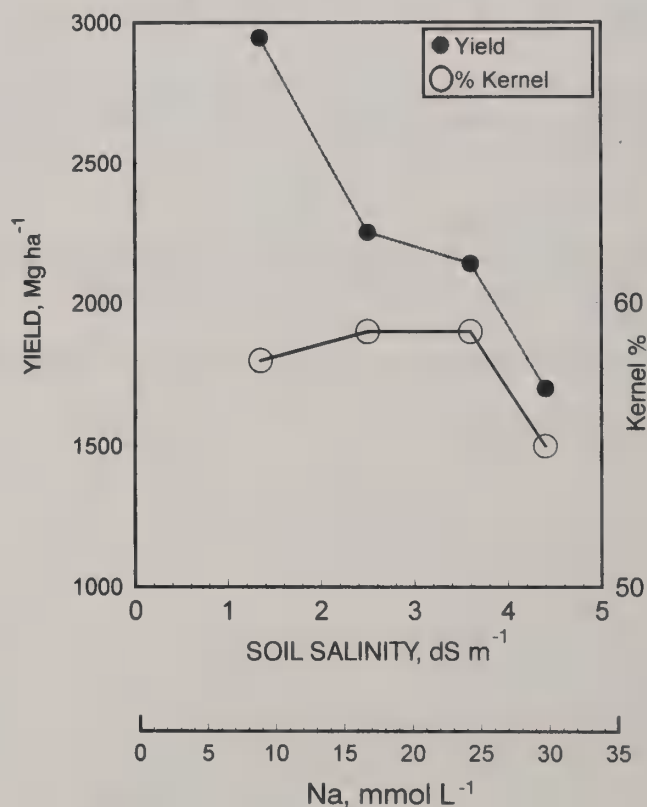
Fig. 4. Nut yields and kernel percentage of "Western" as related to salintity or Na concentrations in the saturation extract in a soil depth of 0 - 60 cm (Miyamoto and Gonzales, 1998, unpublished).
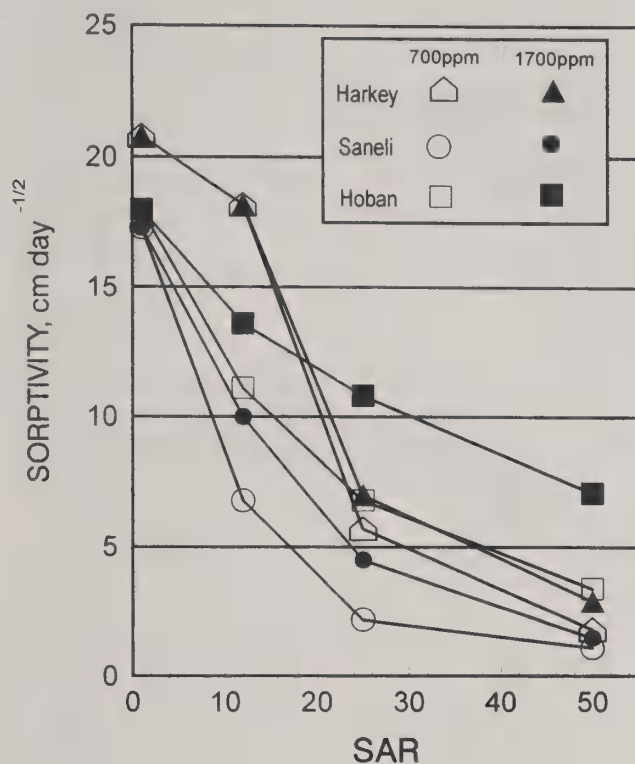
Fig. 5. Sorptivity of selected soils as related to the sodium adsorption ratio (SAR) of irrigating solutions at two levels of salinity.
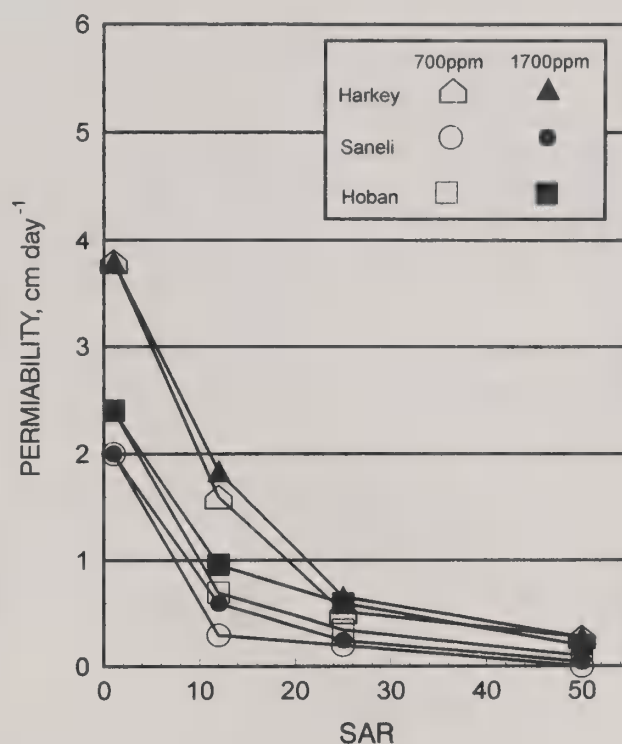
Fig. 6. Permeabitlity of selected soils as related to the sodium adsorption ratio (SAR) of irrigating solutions at two levels of salinity.
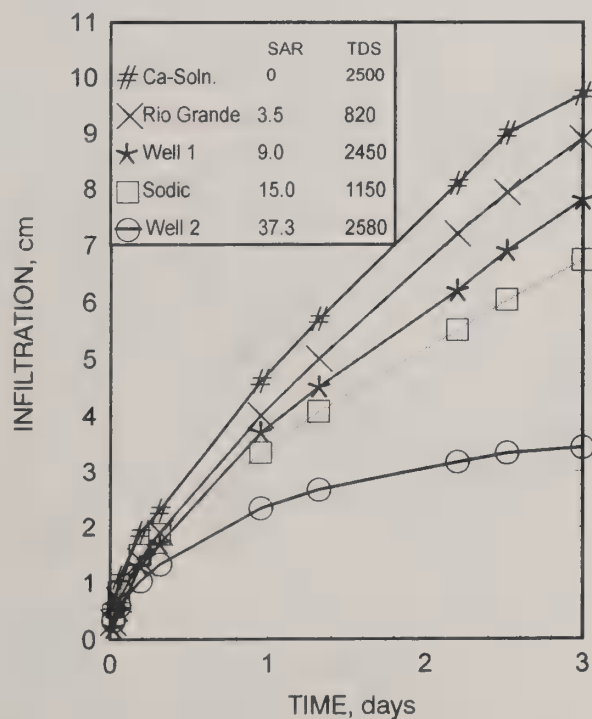
Fig. 7. The cumulative infiltration of the Rio Grande water in Saneli soil previously irrigated with various water sources.
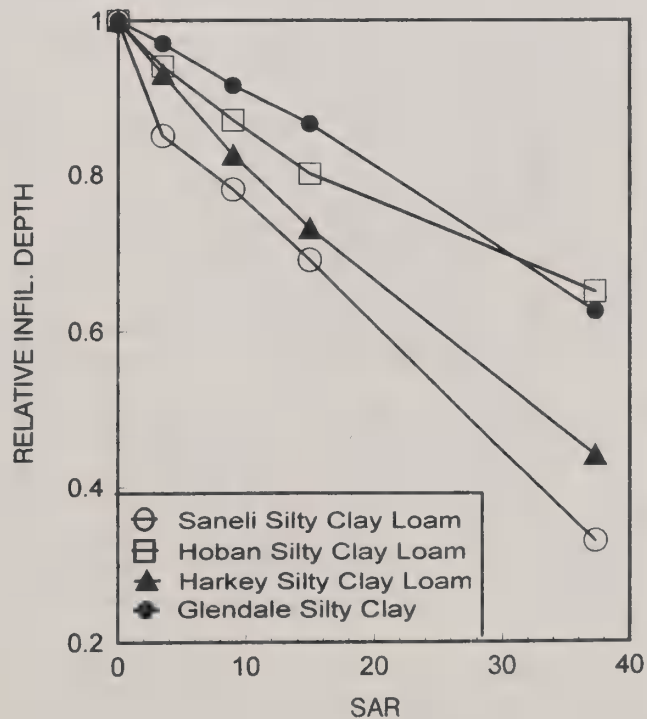
Fig. 8. Relative infiltration depths of the Rio Grande water into soils previously irrigated with various water sources.

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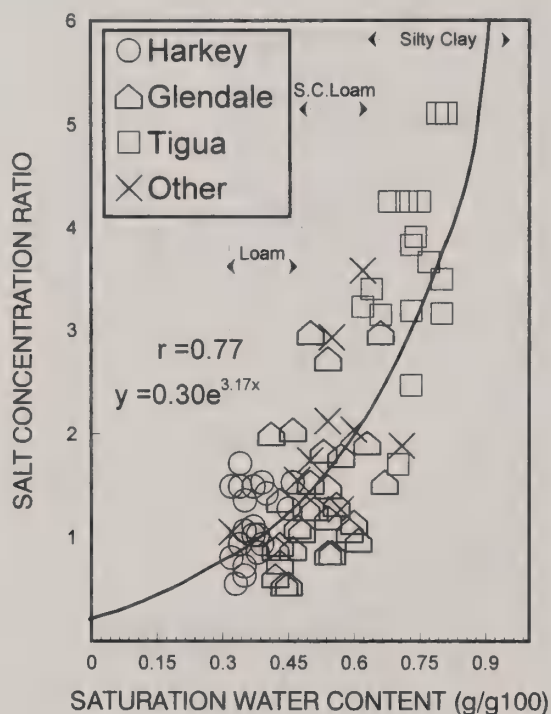
Fig. 9. The observed salt concentration ratios of irrigated soils in the El Paso Valley as related to the saturation water content in a soil depth of 0 -60 cm.
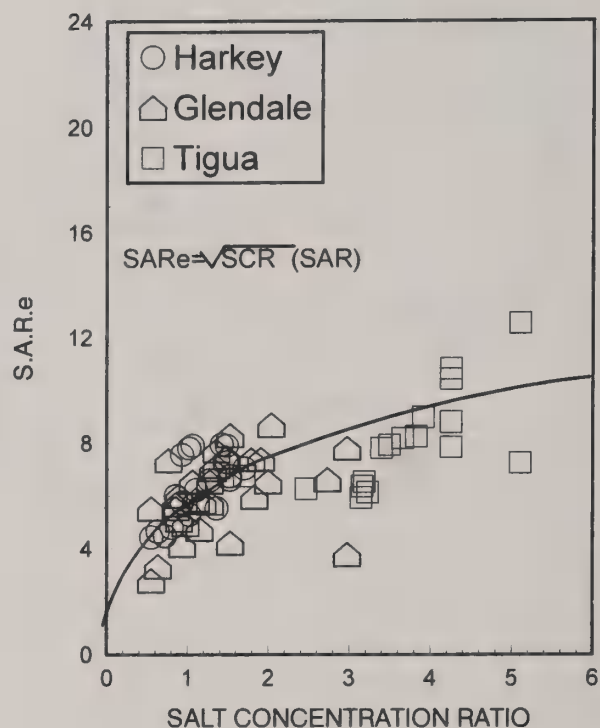
Fig. 10. The observed and predicted relationship between the sodium adsorption ratio of the saturation extract (SAR_e) and the salt concentration ratio.
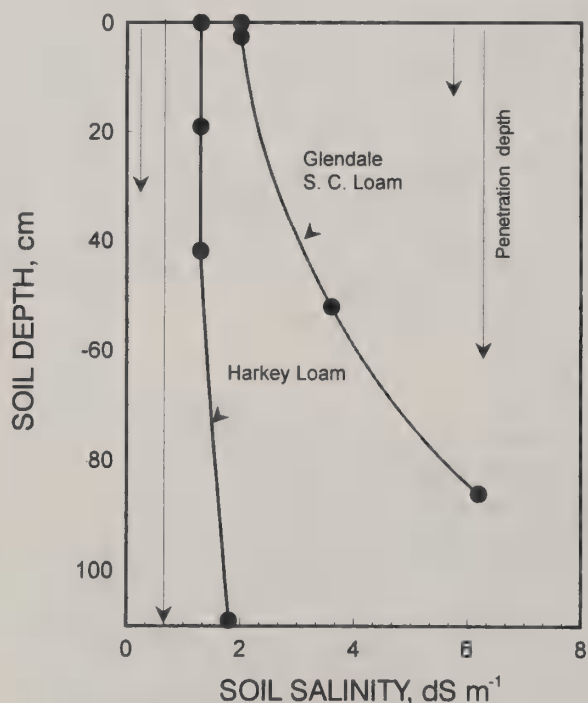
Fig. 11. The estimated depth of water penetration and examples of salinity distribution in irrigated soils: Pecans.
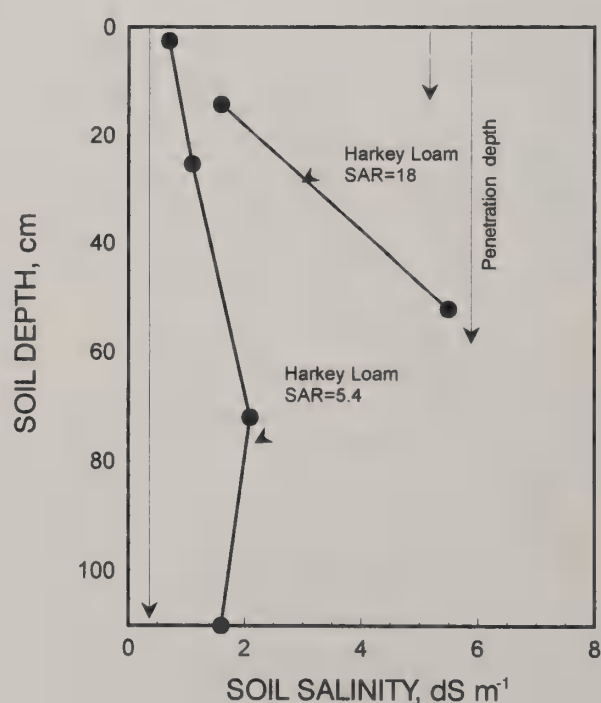
Fig. 12. The estimated depth of water penetration and examples of salinity distribution in irrigated soils: Alfalfa.

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NITROGEN CYCLING AND IMPLICATIONS FOR MANAGEMENT

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Additional index words. *Carya illinoinensis* (Wangenh.) K. Koch, nitrogen accumulation, nitrogen-15, soil nitrogen

ABSTRACT

Ammonium sulfate (1059 kg/ha) enriched with 10.4 atom % ^{15}N was applied to three pecan trees in a commercial pecan orchard in 1996. Soil and tissue samples were collected during the 1996 and 1997 growing seasons. Ten days after the first application of ^{15}N ammonium sulfate, fertilizer N was detected in the soil profile just above the ground water table (280 cm). ^{15}N rapidly accumulated in the early 1996 growth and was a significant portion of the total N in plant tissue through harvest. Fertilizer N applied in 1996 was a significant portion of the N in new growth in 1997. Fertilizer N was probably lost to the ground water table during the growing season. About 4.5% of the applied N was removed from the field with the nuts, 3.2% was in the roots, 4.7% was in the wood, and 6.7% remained on the soil surface as leaf and husk debris. About 35.4% of the N applied in 1996 remained in the soil at the end of the growing season. However, much of this soil N was deep in the profile and would be vulnerable to leaching.

Nitrogen is the most commonly used nutrient in pecan orchards (Hunter and Lewis, 1942; Malstrom, et al., 1983; Storey et al., 1986) and is the most likely nutrient to become deficient during pecan production. Nitrogen is the principal nutrient applied every year to established as well as young pecan orchards (Sparks, 1968; Kilby, 1982; McEachern, 1995). Recommended N fertilizer rates (Sparks, 1972; Worley, 1974; Worley, 1990) and time of fertilizer application (Skinner et al., 1938; Kilby, 1982) have been studied. In New Mexico, recommendations for N fertilization range between 168 - 224 kg N/ha /year with the N split between two

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equal doses applied in March and June (Herrera, 1995). However, the nutritional status of the tree from the previous year may be just as important in determining pecan yields as the nutritional status during the current growing season (Oland, 1959; Conradie, N.J., 1983). No research has been conducted in pecan trees to address this issue partially because of the difficulty differentiating between fertilizer N, soil N, and tree reserve N.

^{15}N fertilizer has been used for several decades to follow the fate of fertilizer N in soil-plant systems. The source of N and the fate of fertilizer N can be determined qualitatively and quantitatively. Nitrogen studies with ^{15}N enriched fertilizer conducted in other woody trees have shed some light on the movement and storage of fertilizer N for the following year (Cooper et al., 1976; Conradie, 1983; Weinbaum and Muraoka, 1986). These studies have proved that stored-N supports the development and function of annual plant organs the year following N application.

The objective of the present study was to evaluate the movement of ^{15}N labeled N fertilizer in soil and the accumulation of ^{15}N in pecan tree parts during the year of application and the following year.

MATERIALS AND METHODS

The experiment was initiated in Spring 1996 in an established orchard located approximately 12 km south of Las Cruces, NM. The 15-year old 'Western Schley' pecan trees were growing on a level, well-drained Agua clay loam (fine-loamy over sandy, mixed (calcareous), thermic Typic Torrifluvent) that formed in mixed alluvium in the Rio Grande flood plain. The clay loam surface graded into a fine loamy sand at about the 45 cm depth. The orchard was flood irrigated at a rate of 1.2 m per year and the water table was approximately 280 cm below the surface.

Three research trees were selected in different rows and were typical of other trees in the orchard. They were similar with respect to canopy cover, trunk diameter, and height. Each of the three trees was the center of a 9 m by 9 m research plot. The three trees were managed (water, pesticides, fertilizers, etc.) like the rest of the orchard except ^{15}N-labeled ammonium sulfate (221 kg N/ha) was applied instead of commercial ammonium sulfate. The research plots were also instrumented with tensiometers and neutron probe access tubes to monitor water potential and water movement.

The ^{15}N labeled ammonium sulfate was from ISOTEC Inc., Miamisburg, OH. The analysis from the

University of Nebraska indicated a total N content of 20.9 % and a ^{15}N content of 10.4 atom %.

Before each ^{15}N application, the three plots were rototilled to roughen the surface and assure quick entry of water and fertilizer. The ^{15}N was hand-applied in six split applications (March 25, April 23, May 13, May 24, June 3, and June 15, 1996), immediately raked-in, and irrigated within 24 hours.

Soil samples were collected with a 3.8 cm bucket auger at depths of 0-30, 30-60, 60-90, 90-180, and 180-270 cm within ten days after irrigation. Three holes were made within each plot at varying distances from the tree. Same depth samples from each of the three holes were combined. Soil samples and leaf samples were collected twelve times throughout the growing season. Sample dates are given on the figures. Other tissues (stems, catkins, husks, nuts) were collected throughout the season as growth dictated. Soil and tissue samples were also collected in March 1997 before the application of the grower's normal fertilizer regime and throughout the season.

Tissue samples were oven-dried at 65°C for 48 hours and ground to pass a 250 μm sieve. Soil samples were air-dried for 48 hours and ground to pass an 150 μm sieve. Ground tissue and soil samples were sent to the University of Nebraska, Lincoln, for analysis. Atom % ^{15}N and total N were analyzed with the Tracermass Stable Isotope Mass Spectrometer (Europa Scientific Ltd.).

Soil samples for background ^{15}N levels were randomly collected prior to the start of the experiment and three times during the 1996 and 1997 growing seasons. Soil from the same depths were composited. The background ^{15}N levels used in calculations were the average of these samples.

Tissue samples for background ^{15}N levels were collected throughout the orchard at each sampling. Leaf background ^{15}N levels varied little and were averaged together. ^{15}N background for other tissue was determined from similar tissue collected elsewhere in the orchard.

The percent recovery of the applied fertilizer was determined for pecan tissue and soil. Soil recovery was based on bulk density measurements, total N, and ^{15}N measurements through the profile. Biomass estimations were necessary in order to determine the percent recovery of ^{15}N in the tissue components. The estimations for biomass were based upon the following calculations for *Carya* ssp. (Brenneman et al., 1978)

and *Quercus velutina* Lam. (King and Schnell, 1972).

Carya spp.
Above Ground Tree Biomass (lb.) = 2.0340 x $D^{2.6349}$

Quercus velutina Lam.
Whole Tree Biomass (Log lb.) = 1.00005 + 2.10621 Log D
Root and Stump Biomass (Log lb.) = 0.38000 + 2.12094 Log D

D = trunk diameter at breast height (1.37 m above ground) as measured in inches.

To confirm the validity of these calculations for *C. illinoinensis*, a pecan tree of similar size to the research trees was sacrificed and tissues collected on a component basis. The above-ground biomass compared favorably to its calculated weight when its diameter at breast height was used in the above equations.

RESULTS AND DISCUSSION

Fertilizer applications and irrigations of the experimental trees occurred when the entire orchard was fertilized and irrigated. The soil profile deeper than approximately 30 cm remained near field capacity the entire growing season as determined by neutron probe and tensiometer measurements (data not shown). Thus, the potential existed for significant leaching.

Immediately after incorporation of the first fertilizer application of 117 kg ^{15}N ammonium sulfate/ha (March 25, 1996), the field was flood irrigated with 11 cm of water. The ^{15}N distribution in the soil profile ten days after fertilization (April 4, 1996) is shown in Figure 1. Background ^{15}N slightly increased with depth. This trend was generally observed at all sample dates (data not shown). Small amounts of ^{15}N clearly moved to the 270 cm depth (just above the water table), although most was still in the upper soil profile. The recovery of ^{15}N applied in the entire profile was 98.6%, with 85.8% remaining in the top 90 cm and 82.5 % remaining in the top 60 cm.

The ^{15}N distribution at the end of the growing season (November 6, 1996) is shown in Figure 2. A total of 1059 kg ^{15}N ammonium sulfate/ha had been applied (March through June). Approximately 35.4% of the N applied was recovered in the soil profile to a depth of 270 cm, but ^{15}N enrichment increased with depth. ^{15}N enrichment was least in the 30-60 cm depth, probably

as a result of plant uptake and leaching to lower depths. ^{15}N enrichment was greatest at the 180-270 cm depth. The ^{15}N levels deep in the soil profile and just above the water table (280 cm) suggest that fertilizer N was probably lost to ground water during the growing season and that the remaining fertilizer N would be vulnerable to leaching.

The ^{15}N excess and total N concentrations in stems, leaves, and catkins on May 2, 1996, 38 days after the first application of ^{15}N and 9 days after the second application of ^{15}N (344 kg ^{15}N ammonium sulfate/ha), are shown in Figure 3. ^{15}N excess is the ^{15}N concentration minus the background ^{15}N concentration. All plant parts were clearly enriched with ^{15}N including the catkins. As expected, the ^{15}N and total N content increased from older stems to younger stems. Data from April 26, 1997 show that the total N was about the same for all plant parts as in 1996, but the ^{15}N content increased from 1996. The higher levels of ^{15}N in 1997 than in 1996 may be partially explained by the application of more ^{15}N in May and June in 1996, after the May 2, 1996 sampling date. The data clearly show that early growth in pecans uses fertilizer N applied the previous year as well as the fertilizer N applied the current year of production. Research in apple trees using ^{15}N has found that N required for new spring growth, flowering, and fruit development was heavily dependent on currently absorbed N, and reserves stored in plant tissues are not used in preference to currently absorbed N (Grasmanis and Nicholas, 1971).

In 1996, total N concentrations in leaves decreased from May to July (Figure 4) as reported elsewhere (Sullivan et al., 1976). However, ^{15}N concentration increased the first three sampling dates. The high levels of leaf ^{15}N after May probably reflect the greater availability of ^{15}N in the ^{14}N-^{15}N pool as a result of additional ^{15}N fertilization in June. By May 23, 1996, 611 kg/ha ^{15}N ammonium sulfate had been applied, and by June 15, 1996, 1059 kg/ha ^{15}N ammonium sulfate had been applied. The increase in leaf total N from mid-July through mid-August probably reflects the accumulation of N after the leaves reach full size. The decline in leaf total N from mid-August through mid-November probably reflects movement of N out of the leaves and into the developing nut and storage areas as has been observed in other nuts (Weinbaum and Muraoka, 1986). The leaf sample on November 15, 1996 was a brown leaf sample and represented the N that would be returned to soil in leaf fall (Oland, 1963).

Leaf ^{15}N excess and total N concentrations for the three sample dates in 1997 (Figure 4) also show enrichment

levels similar to the 1996 levels. The ^{15}N could have come from ^{15}N reserves in the trees or from ^{15}N remaining in the soil from 1996. In March 1997, 23.0% of the N applied (51 kg/ha) remained in the soil profile from 1996. The decline in ^{15}N concentration from May 27 to June 18 probably reflects the greater availability of ^{14}N in the ^{14}N-^{15}N pool as the grower applied unlabeled fertilizer. The remaining samples from 1997 have not been analyzed.

The ^{15}N enrichment and total N of plant components at the end of the growing season (November 1996) are shown in Figure 5. ^{15}N and total N of the wood is not included because of differences in N concentration between small branches, large branches and trunk. The root tissue was small roots recovered during soil sampling. More of the N fertilizer was concentrated in the husk than the other components, that emphasizes the importance of the husk in kernel development (Dozier and Amling, 1974).

Total percent recovery of ^{15}N applied by plant components and soil was about 54.5% (Table 1). Much of the ^{15}N applied remained in the soil at the end of the season (35.4%), and only 19.1% was recovered in plant tissue. If only the nut (kernel + shells) leaves the field, about 4.5% of the N applied was harvested the year of fertilization. About 6.7% of the N applied was recycled (leaves + husks), 3.2% remained in the root, and 4.7% remained in the wood.

CONCLUSIONS

Nitrogen moves rapidly under typical pecan orchard management in the Mesilla Valley. Fertilizer N moves quickly to the ground water table during the growing season if the soil below 30 cm is kept near field capacity. At the end of the growing season, about 35.4 % of the N applied remains in the soil profile above the water table. However, much of this N is deep in the soil profile where it is vulnerable to leaching. Fertilizer N rapidly accumulates in the early growth and is a significant portion of the total N in plant tissue through harvest during the year of application. Pecans use N applied the previous year for growth during the current year. About 4.5% of the applied N is removed from the field with the nuts, 3.2% remains as root reserves, 4.7 % is in the wood, and 6.7% remains on the soil surface as leaf and husk debris.

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Figure 2. Soil profile distribution of ^{15}N in background soil and soil fertilized with ^{15}N (1059 kg ^{15}N ammonium sulfate) on November 6, 1996.

Figure 1. Soil profile distribution of ^{15}N in background soil and soil fertilized with ^{15}N (117 kg ^{15}N ammonium sulfate) on April 4, 1996.

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Figure 4. ^{15}N excess and total N concentration of pecan tree leaves in 1996 and 1997.

Figure 3. ^{15}N excess and total N in pecan trees in 1994 stems (94S), 1995 stems (95S), 1996 stems (96S), 1996 leaves (96L), and catkins (96C) on May 2,1996 and 1995 stems (95S), 1996 stems (96S), 1997 stems (97S), 1997 leaves (96L), and catkins (97C) on April 26, 1997.

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Table 1. ^{15}N and ^{15}N recovery in soil and plant components at the end of the growing season (November 1996). A total of 23 kg ^{15}N/ha (1059 kg ammonium sulfate) was applied.

Soil or Plant Component	^{15}N	^{15}N Recovery[a]
	(kg/ha)	(%)
Soil (270 cm)	8.2	35.4
Leaf[+]	1.3	5.7
Husk[+]	0.2	1.0
Kernel	0.9	3.9
Shell	0.2	0.6
Root[++]	0.7	3.2
Wood[+]	1.1	4.7
Total	12.6	54.5

[a] ^{15}N recovery calculated on the application of 23 kg ^{15}N/ha.
[+] Leaf, husk, and wood biomass were estimated as described by Brenneman et al. (1978), King and Schnell (1972) and validated by sacrificing a tree.
[++] Root biomass was estimated as described by Brenneman et al. (1978), King and Schnell (1972).

Figure 5. ^{15}N excess and total N concentration of pecan tree components at the end of the 1996 growing season.

DISEASE ASSESSMENT AND UNIFORMITY IN RATING METHODS

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ABSTRACT

Disease assessments are routinely made by plant pathologists studying ways to improve disease control. Methods used in making these assessments vary according to the preference of individuals. The variation in assessment methods often makes using data from one location difficult in other locations where different methods are used. This is particularly evident when one reviews data packages put together by companies introducing new products. To further complicate the situation, estimates of disease impact on quality and/or yield are often not made leading one to speculate as to what the disease impact might have been. At times disease assessment data are lumped into arbitrary groups to represent acceptable (commercial) control and non acceptable control. This is usually done with no support data and is to a degree both misleading and meaningless. While scientists usually agree that uniformity of assessment methods and estimates of disease impact are good ideas and even essential to proper communication, individuals cannot be compelled to use any "standard method". All manner of rationalizations are offered as to why standard methods should be used in an "ideal world" but simply cannot be used in a "real world".

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The chief rationalizations are issues of time and convenience. This applies to direct measures of disease impact as well. There is however considerable inconvenience involved where assessment methods are not uniform. When data is not uniformly expressed it becomes difficult to put together a clear package that represents the pecan industry as a whole. The EPA, for example, finds it very inconvenient to use data from six different states where the results are expressed in six different ways. It is very inconvenient to use data from one state to fill a gap in another state when an unfamiliar rating method has been used. There is also a quite correct feeling in industry, regulatory agencies and among plant pathologists that disease assessments alone without some measure of disease impact are quite useless.

This paper proposes to briefly discuss methods of assessing pecan disease incidence, severity and impact. Suggestions as to how methods could be standardized are included.

METHODS

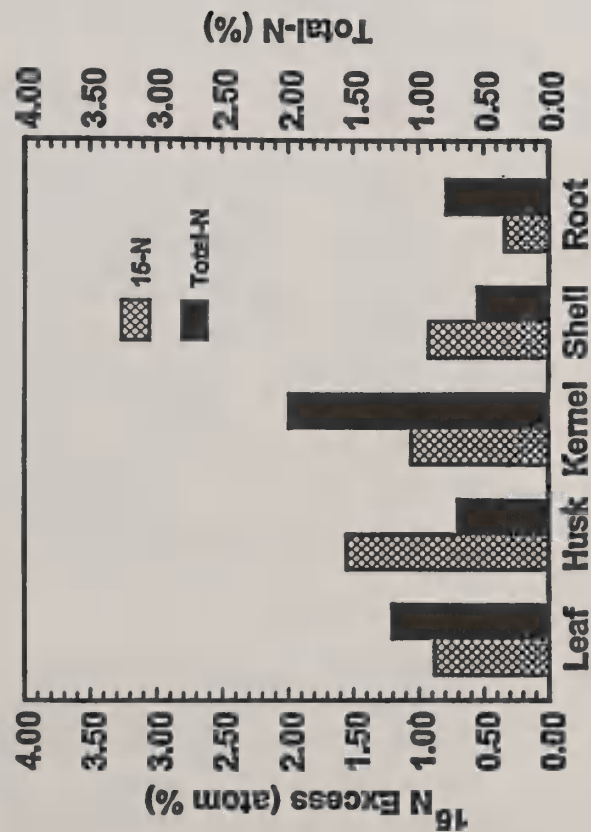**Leaf Diseases.** Several published and unpublished methods of assessing leaf diseases have been used. Leaf disease incidence has been expressed in terms of the percent of leaves or individual leaflets with disease present. This sort of evaluation can be done very quickly and easily. Disease incidence data is most useful when one diseased unit represents on unit of loss. (Brown rot in stone fruit is an example where a rotten peach is a rotten peach whether 1% or 100% rotted). This is not the case however for pecan leaf diseases. The two most common systems for evaluating pecan leaf disease severity have been reviewed (Bertrand and Gottwald 1981).

The difficulty with these systems is two-fold. First; when rating whole compound leaves, disease severity is seldom enough to score a leaf above the three (Hunter and Roberts 1978) or four (Horsfall and Barratt 1945) lowest rating categories. Evaluating each individual leaflet may improve precision but takes considerably more time. Secondly there is no data to connect any level of disease severity with disease loss. Estimates of downy spot (Loustalot and Hamilton 1941) and scab (Gould et. al. 1996) severity on leaf physiology have been made. There is however no data on how these changes in leaf physiology effect yield or quality of pecans. In a downy spot study in 1996 (Bertrand unpublished) it was found that various levels of downy spot severity on terminals had no effect on nut size, quality or retention. In this study there was not the usual defoliation associated with downy spot. It is possible that the only damage from most leaf diseases is derived through defoliation. It has been demonstrated that late season defoliation by artificial means will reduce crop quality and quantity the following season (Worley 1979a, 1979b). Such data is lacking for defoliation caused by any disease. Pecan scab and possibly powdery mildew present a more complicated situation than other leaf diseases. With these diseases it is assumed that in addition to what ever unknown levels of leaf damage may occur, lesions serve as a source of inoculum for nut infections. There is no data however that links any particular level of leaf disease severity with any level of subsequent nut disease severity with either pathogen.

Severity of leaf disease can also be assessed by lesion counts. This can be very time consuming. It also becomes difficult when lesion counts begin to exceed 100 per compound leaf. At this point time consumption is extreme and precision is lost as it becomes impossible to separate large lesions from a coalescence of smaller lesions. Sporulating scab lesions may vary from 1 to 6mm in diameter thus simple lesion counts do not accurately reflect sporulation potential.

There is often not a good correlation between increasing disease incidence and increasing disease severity. In looking at pecan scab over the years the authors have observed that on sprayed or unsprayed trees most of the scab on terminals occurs generally on the same leaflet pairs on the same leaves. Thus differences in disease incidence may not separate treatments the same way as differences in disease severity (Table 1).

There is no clear best way to rate leaf diseases. An expanded scale such as the Horsfall-Barratt system should provide greater precision than the more compact scale of the Hunter-Roberts system. Precision can be increased along with assessment time by evaluating each individual leaflet. Some effort must be made to connect leaf disease severity with defoliation or some other measure of disease impact.

Nut Disease. Nut disease has been assessed by measuring incidence and/or severity. Disease incidence may be used to separate treatments when overall disease pressure to low as in dry seasons. However, disease incidence has no relation to disease damage except in the crudest possible terms. Nut disease severity is evaluated by the rating scales previously discussed (Horsfall-Barratt and Hunter-Roberts) or local variations of these scales. Actual % of shuck surface covered by disease is also used as a measure of nut disease severity. Any of the methods

provide good correlations with nut quality as measured by nut size (Table 2). The relationship between severity estimates and quality as measured by % kernel is much less clear (Table 3). In the case of pecan scab, nut drop is also related to disease severity when severity becomes fairly high (Table 4). Disease severity is only partly related to yield and quality of pecans. It has been demonstrated that the greatest impact on the crop occurred with early infection (Gottwald and Bertrand 1983). One would expect that greater scab severity at shell hardening would be associated with earlier infections. This is a generally but unfortunately not absolutely true statement.

While there is no obvious "best" way to evaluate leaf disease, pecan nut disease may present a different situation. Expressing pecan nut disease severity as actual % of the shuck covered has several advantages. First, ease and convenience. Working with pecan scab the author has found in using rating scales a tendency to estimate the % coverage and then score the nut into the proper rating scale category. Simply recording % coverage avoids the mental conversion. Others may visualize a grading scale directly and this advantage real or not is actually minor. Second, actual % coverage is much more useful in presenting accurate disease progress analysis than data based on rating categories that do not reflect equivalent groupings, e.g, 0%, trace-6%, 6-25%, 25-50%, etc. Third, perhaps most important, our clientele (farmers, industry and regulatory personnel) can much more easily visualize the difference between 12% vs. 50%, shuck coverage than the difference between a category 3 vs. 5 in some rating scale. Rating scale values just do not mean much outside those using the particular scale.

Disease Impact. Assessment of disease incidence or severity has limited value unless connected to some estimate of disease impact. There is no data connecting any specific leaf disease to disease impact. The work of Worley (Worley 1979 a,b) suggests an impact of defoliation but defoliation data is almost never given as a part of leaf disease assessments. The situation with nut disease, particularly scab is different. Severity of nut scab is correlated with nut size as expressed by nut length or number of nuts per pound (Table 2). Nut length data is very time consuming to gather and has limited meaning to producers. Number of nuts per pound is easier data to generate and has great meaning to producers. However pound count data only implies size and the accuracy of the implication is only as good as the uniformity of the % kernel values. Where % kernel is variable it is difficult to take into account how this difference effects the pound count and how pound count reflects size. Differences in nut scab severity are not always correlated with differences in % kernel. Based on individual nuts there appears to be a consistent though fairly small effect of scab on % kernel (Stevenson and Bertrand unpublished). When 50-100 nut bulk samples are used these effects are not always seen (Table 3). Crop load, moisture availability, and other factors appear to affect % kernel more than scab and it is all but impossible to totally account for these factors.

Pecan disease may also effect yields. Yield can be measured by entirely harvesting plots which is very time consuming and not generally practical. Yield can also be estimated fairly accurately (Worley and Smith 1984). Accuracy of yield estimates are very much subject to tree uniformity. Trees under twenty years old are usually fairly uniform and it is fairly easy to

eliminate obviously "different" trees. Mature trees (>50 yrs. old) tend to be very non uniform and many more trees are required to estimate yield with accuracy. Yield estimates are also influenced by the on year/ off year variation in individual trees which increases with tree age. Where actual yield data can not be gathered relative differences in disease loss in test plots can be obtained from determining differences in nut drop and weight/size values for remaining nuts. Nut drop % can be determined from numbers of nuts and nut scars on peduncles at various times during the season. Such data can allow calculation of relative disease losses between treatments where the best treatment is considered to have no loss.

DISCUSSION

Pecan disease assessments are done in a variety of ways. A grading scale may be the best way to evaluate leaf disease but there is no data relating leaf disease incidence or severity to disease loss. The same grading scales used for leaf disease assessments are used to make nut disease assessments. Actual % shuck coverage may be a better way to evaluate nut disease. Data gathered in this manner are more useful in showing disease increase over time and easier for a non plant pathologist audience to visualize. Measurements of disease impact are critical to any project where differences in disease are to be presented in any meaningful way. As input costs increase faster than commodity prices, farmers are becoming more aware than ever of the need to get tangible value for every input dollar. Pesticide development costs are rising every day. Industry needs good data on the relationships between reduced disease severity and reduced disease loss to help drive decisions on target markets for new

products or continued use of old products. State and Federal regulatory agencies need clear pesticide impact data to justify new use and continued use of chemical pest management options.

Uniformity of assessment methods makes all data more useful beyond individual local needs and is very important.

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Table 1. Rating pecan leaf scab by severity and incidence on Desirable pecan in 1997[1]

Treatment (amount per acre)	% Leaflets with Scab	No. Scab Lesions Per Leaflet
Dodine (1 lb) + Enable (4 ozs)	9.6 A	<0.1 A
Super-Tin 80 WP (7.5 ozs)	75.3 B	4.8 B
Check	81.4 B	16.5 C

[1]In each column means followed by a different letter are significantly different (p=0.05).

Table 2. The effect of nut scab severity on final nut size in Desirable pecan[1]

Treatment (Amount/Acre)	% Shuck Covered with Scab				Nut Length (mm)	# Nuts/Lb	% Kernel
	10 June	1 July	26 July	19 Aug[2]			
DOUGHERTY COUNTY							
Super-Tin (1/2 rate) + Enable (4 ozs)	0.27 A	0.4 A	3.5 A	10.7 A	39.9 A	55.5 A	54.7 A
Dodine (1 lb) + Enable (4 ozs)	0.22 A	0.4 A	4.8 AB	13.1 A	38.8 A	56.5 A	54.6 A
Super-Tin/Orbit Co-pack (as label)	0.23 A	0.6 A	6.5 B	14.5 A	38.3 A	55.8 A	54.5 A
Super-Tin 80WP (7.5 ozs)	0.01 B	1.4 A	10.6 C	24.1 B	36.4 B	62.8 A	54.2 A
Check	0.54 C	16.9 B	86.6 D	90.1 C	30.7 C	110.5 B	50.2 B
MITCHELL COUNTY II							
Super-Tin (1/2 rate) + Enable (4 ozs)	0.04 A	0.23 A	4.3 A	10.2 A	39.2 A	67.3 A	49.4 A
Dodine (1 lb) + Enable (4 ozs)	0.02 A	0.22 A	3.8 A	8.7 A	38.2 A	69.9 A	49.5 A
Super-Tin/Orbit Co-pack (as label)	0.02 A	0.35 A	9.0 B	19.2 B	38.2 A	67.5 A	49.1 A
Super-Tin 80WP (7.5 ozs)	0.02 A	2.12 B	26.5 C	40.6 C	35.2 B	85.4 B	47.7 A
Check	0.18 B	15.63 C	84.1 D	71.2 D	32.5 C	91.1 C	49.4 A

[1]For each location numbers in the same column followed by a different letter are significantly different (p=0.05).
[2]Shell hardening

Table 3. The inconsistent effect of nut scab on % kernel in 50 nut bulk samples of Desirable pecan

Location[1]	Treatment	Nut Scab[2]	% Kernel
Mitchell County	Check	61.9 A	46.6 A
1994	Treated	8.4 B	48.7 A
Berrien County	Check	64.0 A	45.7 A
1994	Treated	11.7 B	45.1 A
Lee County	Check	56.9 A	44.8 A
1994	Treated	10.1 B	52.3 B
Berrien County	Check	25.2 A	51.6 A
1995	Treated	2.8 B	54.5 B
Mitchell County	Check	66.9 A	52.4 A
1995	Treated	18.0 B	53.4 A
Dougherty County	Check	90.1 A	50.2 A
1997	Treated	10.7 B	54.7 B
Mitchell County	Check	71.2 A	49.4 A
1997	Treated	8.7 B	49.5 A

[1]For each location, numbers in the same column followed by a different letter are significantly different (p=0.05).
[2]Average % of the shuck surface covered by scab at shell hardening.

Table 4. The effect of high scab severity ratings on early nut drop of Desirable pecan[1]

Treatment	% Shuck Covered with Scab				% Nut Drop (Aug-Sept)
	10 June	1 July	26 July	19 Aug[2]	
DOUGHERTY COUNTY					
Dodine (1 lb) + Enable (4 ozs)	0.22 A	0.4 A	4.8 A	13.1 A	12.1 A
Super-Tin 80WP (7.5 ozs)	0.01 B	1.4 A	10.6 B	24.1 B	10.8 A
Check	0.54 C	16.9 B	86.6 C	90.1 C	93.7 B
MITCHELL COUNTY					
Dodine (1 lb) + Enable (4 ozs)	0.02 A	0.22 A	3.8 A	8.7 A	24.1 A
Super-Tin 80WP (7.5 ozs)	0.02 A	2.12 B	26.5 B	40.6 B	33.1 A
Check	0.18 B	15.63 C	84.1 C	71.2 C	87.2 B

[1]For each location, numbers in the same column followed by a different letter are significantly different (p=0.05).
[2]Shell hardening

LATE SEASON SHUCK DISORDERS OF PECAN

R. S. Sanderlin[1]

Additional index words. anthracnose, shuck dieback

ABSTRACT

Late season shuck disorders have perplexed pecan specialists and growers for decades as to their description and cause. Confusion about these problems has been exacerbated because of several factors. A variety of different names apparently have been applied to the same symptoms; conversely, different problems may have been assigned the same names. There has been a lack of complete symptom description, which is compounded by variation in symptoms from year to year as well as differences between cultivars. In addition it has been difficult to obtain a definitive association of a specific symptomatology with a single specific cause. In this paper the literature concerning the late season shuck disorders is reviewed, and two distinct symptomtologies are identified. One named anthracnose is typified by necrosis beginning near the proximal end of the nut as a discrete sunken lesion that can spread over the shuck. Nuts with anthracnose often drop shortly after the onset of symptoms. Anthracnose had been reproduced in the lab by inoculations with *Glomerella cingulata*. Shuck dieback generally begins as a necrosis near the distal end of the nut. The entire shuck dies prematurely, and the nuts often remain attached to the terminals. Shuck dieback is associated with various environmental and cultural stress situations such as large crop loads.

All of the literature that comes under the umbrella of late season shuck disorders has at least one thing in common. It always describes a necrosis of the shuck that begins anywhere from around early August to nut maturity. Unfortunately, beyond the recognition of shucks becoming necrotic in late summer and early fall there was not always a detailed description of the symptoms given. The first published account of such a problem on the nuts was by Frederick Rand in 1914 (Rand 1914). The problem occurred in several southeastern states, and was reported as sunken necrotic spots on the shucks. Nuts with this necrosis often dropped from the trees. No particular location of the spots on the shucks was mentioned. The fungus *Glomerella cingulata* was isolated from these shucks and the necrosis was reproduced by inoculations in the lab. Rand named the problem anthracnose disease. In addition to the necrosis of the shucks, *Glomerella* also was reported to cause reddish brown lesions on the foliage (Rand 1914).

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During the late '60s and early '70s, Pete Schaller and Glen KenKnight, working at the USDA Pecan Station in Louisiana, published several papers in which they described late season shuck problems on pecan (Schaller et al.1968, Schaller 1971, Schaller and KenKnight 1972), they worked primarily with the 'Success' cultivar. In the last of these papers published in 1972 they recognized two distinct patterns of symptoms of shuck disorders (Schaller and KenKnight 1972). One of the patterns was a necrosis of the shuck beginning at the proximal end of the nut. The necrosis could spread to cover the entire shuck. The shuck thus affected would often stick to the shell of the nuts. They termed this problem 'stem-end blight'. Because the results of their tests made during two years indicated that applications of benomyl beginning in early August reduced the incidence of this malady they suggested that a fungus might be involved in causing the symptoms. They did not mention any specific fungus. They also described another pattern of shuck necrosis in which the shuck begins to turn black near the distal end of the nut. This symptom was associated with an excessively large crop. They termed this problem 'shuck dieback'. Both of these problems could occur at the same time and even on the same nut. In addition to the end of the nut on which the necrosis began, another common difference was that nuts with stem-end blight often had the shuck stick to the shell, while nuts with shuck dieback typically had the shuck flare open (Schaller and KenKnight 1972). It has been my observation that these are general tendencies but not absolute distinguishing characteristics; sometimes the shucks of nuts with either malady can stick to the shell or flare open. Schaller and KenKnight indicated in this paper that a variety of terms had been applied to late season shuck disorders and suggested that the term 'shuck disease' had been used in a general sense for any and all late season shuck necrosis and should not be used any longer. Unfortunately, this suggestion has not been followed.

In the late '70s and early '80s, it was reported from Texas that stem-end blight was caused by *Botryosphaeria* (Halliwell and Johnson 1978, Johnson 1980). However, I could not find any report on the confirmation of infection by inoculation studies. These same reports also indicated that shuck dieback appeared to be physiological and not involve a pathogen. The association of *Botryosphaeria* with stem-end blight was similar to a report from India in 1974 in which a nut rot was reported to be caused by this fungus (Saharan, 1974). The symptoms described for the nut rot of pecan in India caused by *Botryosphaeria* were different from the symptoms reported for late season shuck diseases in the U. S. in that numerous lesions on the shuck coalesced to completely cover the nut, and a watery exudate was often present with the rot.

Brenneman and Reilly described a late season problem of pecan that started with necrosis at the proximal end of the nut and in which the shucks often stuck to the shell (Brenneman and Reilly, 1989). *Glomerella cingulata* was isolated from these nuts and the disease reproduced by inoculation with *Glomerella* in lab tests. This was the fungus described as the cause of anthracnose by Rand in 1914. The symptoms described by Brenneman and Reilly

for anthracnose were very similar to the symptoms described as stem-end blight by Schaller and KenKnight (Schaller and KenKnight, 1972). Anthracnose and stem-end blight are probably the same phenomenon, and because the name anthracnose predates the term stem-end blight, anthracnose should be the proper name applied to this problem.

Reilly most recently indicated that not only could *Glomerella* inoculations produce the symptoms of necrosis beginning at the proximal end of the nut but that inoculations with another fungus isolated from pecan, a species of *Phomopsis,* also could reproduce the symptoms of anthracnose (Reilly 1994) . Additionally lab inoculations with either fungus could produce necrosis that began at the distal end of the nut (Reilly 1994). Prior to this it had been suggested by others that the necrosis beginning at the distal end of the nut was a physiological response to stress (Schaller and KenKnight 1972, Halliwell and Johnson 1972, Sanderlin, 1989).

A study of the incidence and damage caused by anthracnose and shuck dieback was conducted over a five-year period at the LSU Pecan Station from 1980 through 1984. The test was on cv. 'Success' trees that were about 50 years old. Comparisons were made on the occurrence of shuck dieback and anthracnose between trees that were not treated with fungicide and trees that received benomyl applications full season. Fungicide applications were made on a 3-4 week schedule from April through August. Insecticide and fertilizer applications were the same for all trees in the test each year. The same treatment was applied to the same individual test trees throughout each year of the test. There were twelve trees that received benomyl applications each year and six that got no fungicide. Each year twenty nut-bearing terminals were tagged on each tree and monitored regularly for shuck problems. Nut clusters on both the perimeter of the tree limbs and on the interior of the tree were tagged and the clusters varied in location from 8 feet to 50 above ground.

In four of the five years the trees treated with benomyl had a significantly lower number of nuts with anthracnose than the untreated trees (Table 1). The year without a significant difference (1984) apparently occurred because the incidence of anthracnose was low on the untreated trees. At the same time, the incidence of shuck dieback was significantly lower in only one year (Table 2). In two of the five years, the incidence of shuck dieback was higher on the benomyl-treated trees. This seems to support the observation that shuck dieback is a separate problem from anthracnose (Sanderlin 1989). The effect of both anthracnose and shuck dieback on nut weight in this test was variable and depended on when symptoms began to occur. If symptoms began before the end of September, the reduction in nut weight was significant. The closer the onset of shuck necrosis to the time of normal shuck split the lesser the effect on weight. Anthracnose caused a significant reduction in nut weight in three of the five test years, and shuck dieback reduced weight significantly in two of the years (Table 3). Over the five-year period of the test these two problems each reduced the average nut

weight by 12 percent (Table 4). In addition to this circumstantial evidence that anthracnose and shuck dieback are separate entities is the observation that some orchards have both problems commonly occurring in them while others were observed with primarily the shuck dieback syndrome with anthracnose appearing rarely. Overall shuck dieback is observed more frequently than anthracnose in orchards in LA (Sanderlin 1989). It is important to realize that in the advanced stages of development shuck dieback and anthracnose cannot be distinguished from one another by their appearance.

There is some additional empirical evidence that correlates the shuck dieback problem with a physiological response to various stresses on crop development. The primary stress factor associated with shuck dieback is an excessive crop; this was originally reported by Schaller and KenKnight when they separated the two symptomtologies (Schaller and KenKnight 1972). This also was noted in work from Texas (Halliwell and Johnson 1978). Shuck dieback symptoms were induced by girdling the peduncle or treatment with ethylene (Halliwell and Johnson 1972). The most recent circumstantial evidence for stress induced by a large crop causing shuck dieback was presented by Sparks and co-workers (Sparks et al. 1995). They demonstrated that the incidence of shuck dieback on cv. 'Wichita' could be significantly reduced on a large crop by mechanically thinning the crop during the liquid endosperm stage of nut development. In their work they referred to late season shuck necrosis as shuck decline. They described shuck decline as initially beginning as a thin necrotic line in the shuck tissue at the junction of the shuck to the shell. Soon the entire shuck becomes necrotic. They did not indicate that necrosis began at either end of the nut, and apparently the entire shuck develops necrosis at the same time. However, the final stage of shuck decline as demonstrated in photos appears very much like the final stages of shuck dieback (Sparks et al. 1995). It is probable that shuck decline and shuck dieback are the same problem with differences in appearance the result of cultivar and other variations. Photos of shuck decline from Arizona on cv. 'Western' look identical to shuck dieback on cv. 'Success' described from Louisiana. Because shuck dieback was the original term used to describe this pattern of necrosis and has been commonly used in the literature since 1972, it should be retained in place of shuck decline to avoid addition confusion.

In summary, the situation with the late season shuck disorders is still somewhat murky; thus additional research is needed. But it appears that at least two distinct symptomtologies exist. One of these, anthracnose disease, is associated with one or more fungal pathogens. Evidence from several publications indicates that *Glomerella cingulata* is a pathogen involved in anthracnose development (Rand 1914, Brenneman and Reilly 1989, Reilly 1992, Reilly 1994). Two other fungi also have been implicated (*Botryosphaeria* and *Phomopsis)* (Halliwell and Johnson 1978, Reilly 1994) in anthracnose. For the other shuck necrosis pattern, referred to as shuck dieback, circumstantial evidence has been collected by several workers that suggest it is a separate problem from

anthracnose and may be a physiological response to cultural and environmental stresses (Schaller and KenKnight 1972, Halliwell and Johnson 1972, Sparks et al 1995, Sanderlin Table 1 & 2). The possibility that fungi also are involved in development of shuck dieback has been demonstrated (Reilly 1994).

In addition to the late season shuck disorders anthracnose and shuck dieback, there are other problems that can cause the shuck to become dark during late summer and fall. These include Phytophthora nut and kernel rot (Reilly and Hendrix 1989), water split, mechanical damage, and shuckworm feeding. Fortunately these problems are usually easily distinguished from anthracnose and shuck dieback.

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Table 1. Percent of nuts with anthracnose disease. Benlate treatment applied on a 3-4 week schedule from April through August (1.0 lb/acre). Check trees received no fungicide. Statistical significance based on LSD (P=0.05).

TREATMENT	PERCENT OF NUTS WITH ANTHRACNOSE				
	1980	1981	1982	1983	1984
BENLATE	3.8	3.2	5.6	11.2	1.1
CHECK	30.2	26.1	21.1	45.5	4.3
STATISTICAL SIGNIFICANCE	YES	YES	YES	YES	NO

Table 2. Percent of nuts with shuck dieback. Benlate treatment applied on a 3-4 week schedule from April through August (1.0 lb/acre). Check trees received no fungicide. Statistical significance based on LSD (P=0.05).

TREATMENT	PERCENT OF NUTS WITH SHUCK DIEBACK				
	1980	1981	1982	1983	1984
BENLATE	10.5	38.0	8.2	33.4	15.3
CHECK	19.5	25.2	25.4	25.4	19.5
STATISTICAL SIGNIFICANCE	NO	NO	YES	NO	NO

Table 3. Weight of nuts that had either shuck dieback or anthracnose disease compared to the weight of nuts with normal (healthy) shuck split. LSD (P=0.05).

	IN-SHELL WEIGHT (grams)				
VARIABLE	1980	1981	1982	1983	1984
SHUCK DIEBACK	8.11	8.31[A]	7.79[A]	5.51[A]	8.55
ANTHRACNOSE	8.28	7.33[B]	8.52[B]	6.35[A]	7.64
NORMAL	9.23	8.61[A]	9.13[C]	7.35[B]	9.25
LSD	NS	0.45	0.52	0.93	NS

Table 4. Effect of anthracnose and shuck dieback on nut weight (five-year average, 1980-1984).

	MEAN IN-SHELL WEIGHT (grams) FOR 5 YEARS	PERCENT DEVIATION FROM NORMAL
SHUCK DIEBACK	7.65	-12.2
ANTHRACNOSE	7.62	-12.5
NORMAL	8.71	-

DEVELOPING A RETAIL MARKET FOR PECANS - A CASE STUDY

Scott Landgraf[1]

INTRODUCTION

In 1965, my father, the late Bill Landgraf began grafting small pecan trees along Huauni and Turkey creeks in South Central Oklahoma. He was accustomed to the small native pecans that had grown along those creeks all of his life. The new varieties that were available to him then provided a whole new future to pecan management and marketing.

He studied the attributes that the USDA varieties made available to him. He chose varieties such as Choctaw, Mohawk, Graking, Barton, Wichita and Comanche. Little did he know some varieties were a mistake, while others would develop into winners. By the early 70's, Bill was harvesting enough of the new varieties to start marketing them.

The nuts from the vigorously growing trees were high quality that brought referrals and return visits. My mother, the late Leota Landgraf, marketed the pecans out of her garage. Leota enjoyed the customers and their visits, while generating income for the family. The volume of pecans that were sold out of the garage grew every year.

Bill continued to learn more about spraying, fertilizing, and growing consistent crops of large quality nuts. By the mid 70's, he started wholesaling the surplus nuts to move the volume of pecans he was growing. It was not a problem to find markets for those nuts. It was more of a problem of how to divide them among the vendors.

At this point, wholesaling was probably the best option. Location of the family home lacked visibility and accessibility by the public. Customers had to be familiar with the area in order to get there. Leota's health began to fail. This caused a problem with her continuance in aggressive marketing. Wholesaling was the marketing strategy that best fit the next few years, while maintaining only limited sales though the garage.

A NEW ERA

In 1976, Janice and I started our first planting of pecan trees. Bill furnished us with Choctaw and Mohawk wood to graft the seedling trees we planted. I had

decided that with a limited budget, it was better to spend money on an irrigation system than grafted trees. At the time, little did I understand the significance of irrigation in producing quality nuts. The thought at that time was only to insure tree survival.

During the late 70's, Janice and I were pleasantly surprised at the growth of the new planting and the potential income that it provided our family. With the birth of our three sons during that period, we planted more acres of pecan trees in 1979, 1980, and 1981. As the trees grew, so did the boys.

In 1982, Janice sold our first pecans of any significant quantity off the carport. That was the beginning of Janice's pecan marketing career. Pecan volume continued to increase and the significance of the income continued to draw attention to the pecan enterprise.

With the failing health of my mother and her lack of ability to keep the pecan store open, the garage, Janice and I asked to move the business to our farm shop in 1985. We agreed to include Bill's pecans in the marketing process in exchange for their customer base. The first year or two, Leota very much enjoyed coming to the pecan shop and visiting with her customers.

The business, trees, and boys have all grown over the last 12 years. We have irrigated, sprayed, fertilized, pruned, and harvested together. It has become an even greater pleasure for the boys since they could help Janice collect the money in the pecan shop. They have grown to realize the importance of the retail market to the pecan operation.

THE FUTURE

We were forced to decide how to thin the first planting in the spring of 1996. We pruned and transplanted 27 large pecan trees. The success of the first transplanting was rewarding. We followed that move with transplanting another 300 the spring of 1997.

In 1998, we moved another 151 trees that we were equally pleased with the results. We are now about half finished with the transplanting and/or thinning process. When finished, we will have some 2000 trees spaced over about 125 acres.

The current production has forced us to upgrade the cleaning and drying facilities. In the process, we are incorporating the pecan shop in the same building with the cleaning, drying, and shelling processes. The structure is being erected on highway 70, west of Madill, Oklahoma. It provides the visibility and

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customer convenience that will allow Janice to continue building the pecan business.

Each step has been part of the strategic plan to grow the retail market as the production increases. It has been a long and laborious process. Fortunately, we have sold very few pecans through grade and yield. We have found that wholesaling to roadside stands and other pecan shops in the area is an adequate outlet for excess nuts.

THE STRATEGY

Our policy has been and always will be "Satisfaction Guaranteed or your money back". The marketer, Janice, will not tolerate marginal quality. However, she and the producer, Scott, have a difference of opinion when it comes to thinning nuts; at least for a little while. The marketer wants high quality nuts for satisfied customers, repeated purchases, and customer referrals. She has been so successful in this area, the producer does not have a leg to stand on. We shake to thin the nuts to market, rather than for maximum yield.

That is a conflict that I am not sure can be resolved in the industry. It has been resolved on the integrated operation described here. Of what value are marginal quality nuts to "Landgraf Farms?" Those are the ones sold on grade and yield. Even if nuts are in short supply and have to be replaced, they are wholesaled off the farm. The strategy in production is to grow only nuts that are top quality.

We have traditionally sold inshell pecans, which evolved into providing the cracked and blown process. There were extensive steps required to move from inshell to cracked pecans. Then from cracked to cracked and blown was even a greater step. Now with the construction of a new building, we have incorporated a shelling room. Moving into finished pecan meat products will be an even larger move than all the others combined.

Janice has bought shelled meat and offered them in smaller quantities for resale the last several years. We feel shelled meat products are the trend of the future. The move is necessary to keep up with production. If marketing sets still, production will overcome market growth.

With the increased acres of pecan trees, the marketing has to make a giant move at the same time. We have started to build a 9,000 square feet pecan processing facility with highway frontage. Currently, there has been very little visibility or advertising. We feel the building with signs will provide the visibility necessary to grow markets for the next few years.

We realize that somewhere there may have to be some advertising. We are not inclined to spend money for advertising until our strategy has been completed and proven inadequate. Until that time, we will continue to depend on repeat business and referrals. That has been the pecan shop's connection with its limited success!

PECAN USER EXPECTATIONS

Wojciech J. Florkowski

The currently observed trends in the food market stress the importance of consumer preferences in determining what products enjoy sustained demand. Modern lifestyles are characterized by increasing mobility, access to information, and demand for variety in foods and activities. Pecans fit in this lifestyle because of their many uses in traditional snacks and dishes, and they conform to new cooking styles shaped by health-conscious and educated consumers. Moreover, pecans can be added to many dishes without requiring lengthy preparation (for example, salads, dessert toppings). The insistence of many consumers on convenience makes pecans even more desirable, particularly if used judiciously in accordance with the dietary guidelines.

The dynamic and competitive food market requires constant monitoring and forces adjustments in the production, marketing, and distribution of any food product. The Pecan Industry must recognize that the on-going changes create opportunities for increasing the demand for pecans. To take a full advantage of these opportunities, the Pecan Industry must make genuine efforts to provide pecans or pecan-containing products that meet buyers' expectations. Buyers of pecans include food manufacturers and retail consumers, with the former utilizing about 2/3 of the annually supplied pecans.

The continuing economic viability of the Pecan Industry depends on open communication across all marketing and production levels and focusing on supplying product of a consistent value to all types of users. Goals shared by all industry segments allow the research and outreach support at public and private institutions to concentrate in areas making the largest monetary contribution to the enhancement of attributes demanded by pecan users. Tight research budgets, limited outreach resources, and fragmented industry initiatives call for careful consideration of every project complicated by the long term nature of the investment in pecan production. Therefore, this paper aims at providing information for the decision making by the Pecan Industry rather than offering specific and immediate solutions. Variable climatic and soil conditions, cultivar mix, varied orchard size, and multiple uses of kernels leave the business decision in hands of a grower, an entrepreneur, and a firm manager, while facilitating access complete, timely, accurate, and reliable information.

THE DATA

The discussion presented in this paper is based on the knowledge of commercial users' experience with pecans and their opinions about various characteristics of pecans. In contrast to our earlier surveys, the sample used to gather this information included an array of edible nut users. Given the lack of comparable studies, collected information may more accurately portray the general view of pecans by commercial users than surveys focusing on identifying needs and opinions about pecans expressed by a single industry.

The detailed description of the sample selection, questionnaire design, and survey implementation were provided by Florkowski and Hubbard (1997). A total of 78 firms returned completed questionnaires, i.e. 25.8 % after adjusting the sample size by subtracting firms which could no longer be reached, ceased to exist, or were not involved in nut trade or processing. The frequently lower participation of firms in surveys as compared to households may create doubts about the representativeness of the collected information. However, among publicly available reports, information about issues included in the survey cannot be found. Consequently, our survey is a unique source of information provided by users of edible nuts although the uncertainty with regard to the character of firms omitted from the survey suggests caution in drawing general conclusions.

Tables 1 through 4 provide previously not published summary of responses regarding the profile of the participating firms. A firm trading edible nuts is typically a corporation engaged in business over an extended period of time. For the majority of firms, the value of edible nuts handled exceeded $ 1 mln. Additional discussion of the firms' profile can be found in Florkowski and Hubbard (1997).

According to the data of summary, the majority of the firms were actively trading nuts for at least 26 years. This structure of the industry suggests difficult entry into the industry, possibly due to capital requirements, market information availability, and the market size. The edible nut industry may provide lower returns than other sectors, while institutional arrangements such as the long term business relationships between buyers and sellers may create a barrier for new entrants.

The reported value of edible nut sales indicates that companies trading a large volume of nuts operated for a long period of time, whereas the newcomers start by selling a relatively limited volume of nuts. The ownership structure of the surveyed firms suggests that three-quarters of the surveyed firms were corporations, whereas only 8% were family owned. The corporate structure of a company may be necessary for a successful business to operate and grow for a long period of time.

The general pricing of edible nuts tends to value whole shelled nuts and halves over pieces or meal. According to the survey data, the most desirable form of shelled nuts were

halves when whole nuts were not available as is the case of shelled pecans; halves were preferred by 88.4% of responding firms. The responding firms also indicated that they were very interested in purchasing medium pieces (86.7%) and a smaller percentage was interested in buying large pieces (82.2%). Small pieces were bought by about three-quarters of buyers, while nut meal was the least preferred product. Overall, the edible nut users used whole nuts less frequently than halves or large and medium pieces.

RESEARCH ON PECAN QUALITY

A sequence of studies addressed the expectations of various pecan buyers regarding the quality of in-shell and shelled pecans. Research on pecan quality was conducted on the disciplinary basis. Agricultural engineers addressed the relationship between the percentage of halves recovered from cracking and specific cultivars using the same shelling equipment. An important aspect of that research was the percentage of "stick tights" because of their influence on shelling costs and potential contamination of shelled pecans with pieces of shell or inner lining. Microbiologists researched the link between the presence of cattle in orchards prior to harvest and the bacteria on pecans. Entomologists and horticulturists continue to research cultural practices protecting and improving crop quality. Food scientists and food engineers search for ways to extend the shelf life of pecans or lowering the cost of pecan storage over a short period of time. Economists surveyed all Pecan Industry segments with regard to quality measures of in-shell and shelled pecans. Additional surveys probed major food industries using pecans about quality requirements important to them.

The basis of any expectations was formed by requirements that pecans be free of rancid, rotten nuts, insects or insect parts, or molded kernels. Buyers also demand that pecans be free of foreign material, have no insect damage, and contain little moisture. These quality attributes were incorporated into the standards for grades for in-shell and shelled pecans developed by the U.S. Department of Agriculture, industry organizations, and shelling operations. Some food manufacturers specify their own quality requirements, which may reflect the intended use and the applied production technology.

Expectations about quality attributes, both external and intrinsic, are only a part of expectations formed by pecan users. Users base expectations on their business experience, formal and informal knowledge, opinions and perceptions influenced by others, etc. These expectations build an image of pecans held by an individual or a group of users. Knowledge of user expectations helps in the design and implementation of short term advertising campaigns or promotion efforts persisting over an extended period of time. Given the long term productivity of pecan orchards

and the long period of cultivar development and testing, knowledge of expectations guides the selection of pecan traits leading to improvements of economically important attributes influencing the production and the demand for pecans.

According to the survey summary, nine respondents (11.5 % of the sample) reported having quality problems with pecans on a consistent basis. The figure was relatively higher than for other tree nuts, but pecans were named as the most important nut by the largest portion of respondents. It is possible, therefore, that the incidence of quality problems with pecans could be as high as for other nuts. Among the typical quality problems reported by pecan shellers were rancidity, shell pieces, and the presence of insects or insect larvae in a shipment of shelled pecans. Rancidity was named by five respondents, i.e., almost one-fourth of firms listing pecans as the most important nut to their operations. Four respondents named the presence of shell pieces or insects as a consistently reoccurring problem.

Rancidity can be prevented by proper handling and storage. Careful monitoring of the inventory and rotation of pecans in storage could be used to minimize the probability of shipping rancid pecans. Food manufacturers expect each shipment of be free of shell pieces or insects fearing not only to loose their product image in the eyes of consumers, but being sued by consumers over potential quality lapses. Litigation can be expensive even if the court rules in favor of the company.

Assuring that pecans are free of the above mentioned defects is necessary for mounting an effective promotion or advertising program. The integrity of the product becomes an important factor in sustaining demand for pecans or pecan containing product after the market promotion program is suspended. The suspension, rather than termination of promotion, may be timed to the market developments and implies that promotion will continue. Too often in the past, the Pecan Industry terminated its promotion programs prematurely disrupting contacts and the flow of information to the pecan users. Food manufacturers devote fewer resources to product development and expect with an increasing frequency that growers and shellers will suggest new products and product modifications.

Changing attitudes of commercial pecan users reflected in their expectations shift the responsibility for identifying uses of pecans and buyers of pecan and pecan products on the Pecan Industry. Consequently, the Pecan Industry has to identify expectations of pecan users and consumers to develop programs aiming at segmenting the market for pecans.

WHY USER EXPECTATIONS ARE IMPORTANT?

Many external and intrinsic quality attributes mentioned in the previous section represent fundamental characteristics necessary to facilitate trade and to assure the demand for pecans and pecan products. It is through cultural practices, proper harvesting, handling, and storage that growers and shellers can exercise control over the quality of kernels. However, the demand for pecans is represented by users. Their interpretation of quality attributes may be different than that of the Pecan Industry segments. To maintain and increase the use of pecans, the Pecan Industry must learn what image pecans enjoy among users to improve the efficiency of its promotion efforts. Because the promotion program has been funded by the Pecan Industry, ultimately the industry must communicate its message to users and re-shape the image of pecans in accordance with the sustainable economic goals of growers and shellers.

Participants in the pecan user survey were presented with a list of statements about pecans (Table 5). This list was used in previous surveys of commercial pecan users with the summary of results published in the Pecan Industry magazines. Opinions expressed by participants in this survey add to earlier research providing valuable information for formulating the content of the Pecan Industry's promotion program. Responses obtained about 14 statements were grouped in five major categories in this study; the category names reflect the general character of the statements.

There was little disagreement among respondents that pecan is a good tasting nut which is high in fat (Table 5). However, a sizable portion of respondents was not sure of nutritional attributes of pecans. The recent efforts of the Pecan Industry to strengthen consumer education about nutritional benefits of pecans must be extended to education of commercial users. Furthermore, although pecans are undeniably high in fat, the composition of fatty acids in pecans is highly desirable, yet these facts are little known among commercial pecan users. Reliable information about nutritional value of pecans and their use in a healthy diet must be provided to close the gap between the actual desirable attributes of pecans and their perceptions.

Pecans fit into today's lifestyles, but in opinion of many respondents they seem to be perceived as fitting more often into an old-fashioned pace of life. This poses a dilemma for the Pecan Industry which would like to maintain the traditional uses of pecans, while expanding the range of pecan containing products. The distribution of opinions reflecting expectations of respondents regarding pecans creates an opportunity to segment the pecan and pecan product market. Additional research could help to identify what specific products are associated with modern or old-fashioned lifestyles. According to the results, the majority

of respondents felt that pecans were not just for people with higher incomes implying that pecans appeal to a broad group of users and consumers.

The summary of responses shows that with few exceptions, all participants considered pecan a well know nut (Table 5). Pecans are still perceived as a specialty item, although nearly 14 % disagreed with this characterization of pecans. Because the perception of pecans as a 'specialty item' persists, the information and education efforts of the Pecan Industry could emphasize this particular status of pecans. However, it is likely that pecan users will set high quality standards for a specialty item. This characteristics also has to be reconciled with the issue of how pecans fit into various lifestyles.

Pecans may be perceived as a specialty item depending on the product in which they are used. There is a strong agreement among survey participants that pecans have many uses in baking. Similarly, pecans are perceived as being a traditional ice cream ingredient, although efforts to promote pecans in ice cream have been relatively recent. Pecans' position as a traditional snack is weak: little over one quarter of respondents 'agreed' or 'strongly agreed' that pecans were a traditional snack. This result is consistent with results of similar surveys conducted earlier and suggests that, perhaps, pecan-containing product rather than salted or flavored pecans should be emphasized as potential snacks.

To fully understand the scope of the opinions about pecans, two statements asked respondents about pecan characteristics in relation to other nuts. The summary of responses suggests that a sizable portion of respondents 'disagreed' or only 'somewhat agreed' that pecans tasted better than other nuts, while little over a third agreed with this statement. The observed taste perception in comparison to other nuts becomes even more important when taking into account pecan price perceptions. More than two-thirds of respondents perceived pecans as more expensive than other nuts. Price perceptions can influence the purchasing behavior limiting purchase frequency and pecan use. On the other hand, the Pecan Industry may feel that the prices already are at their lowest level. Consequently, a well thought promotion may focus on pecan-containing products where pecans are only one of many ingredients thus keeping the production costs low.

EXPECTATIONS AND PRICES

The intense competition on food market is mirrored in product pricing. Prices of edible nuts tend to change from season to season in response to the supply. But the supply of many nuts, determined by the size of the crop, cannot quickly respond to market opportunities by regulating the flow of the product from the new crop, inventory, or

overseas suppliers. Edible nut growers and food manufacturers are price takers and must absorb price and revenue fluctuations. Earlier studies of the pecan use provided evidence that price instability and price level were among major barriers for an expanded pecan use. Moreover, the annual fluctuations in pecan production and their influence on price dictate the reaction of food manufacturers. Facing competition, many food manufacturers who use edible nuts in their products, learned to alter product formulations and substitute a less expensive nut for the more expensive, only to reverse the use of a particular type of nut if prices of nuts change.

To escape the price competition, edible nut growers, shellers, and users develop nut-specific products. Such products, supported by promotion and advertising, may allow for market segmentation. The intention of the pecan user is to create a niche where the demand is relatively inelastic allowing the supplier to dampen the downward pressure on prices from increasing supplies of pecans and other nuts. Segmentation allows for charging higher prices than would be discovered on a perfectly competitive market.

Product differentiation is an effective way of establishing a market segment, but requires investment in research leading to a new or modified pecan containing food product. Product development could be expensive and there is no guarantee of consumer acceptance or a sizable market justifying commercial production. Market research of actual or perceived consumer needs that can be met by the existing and new pecan containing products can offer a less expensive alternative to product development. By studying consumer expectations and opinions about pecans and pecan products, the Pecan Industry may identify segments that differ in their needs from the total pecan user population and apply various pricing methods.

THE MEDITERRANEAN DIET AND PECANS

The Mediterranean Diet concept has been developed by the edible nut industry and used in promoting increased consumption of edible nuts. The concept originally was based on increased consumption of almonds and walnuts as well as, to some extent, on consumption of hazelnuts and pistachios. The pecan industry joins the effort of the International Nut Council and introduced pecans into the Mediterranean Diet concept, although pecans are not native to the Mediterranean region. According to the Mediterranean Diet concept, edible nuts are part of a balanced healthy diet based on consumption of complex carbohydrates and large quantity of fruits and vegetables.

Among the surveyed companies 56.8% of respondents were familiar with the concept of the Mediterranean Diet. The Mediterranean Diet concept, although well developed, has not been popularized among the general public or edible nut

processors. Therefore, its impact on sales and revenues has been limited. The lack of such information seems to be responsible for the relatively low familiarity with the Mediterranean Diet concept. The emphasis on the use of nuts native to the Mediterranean may be among factors influencing the use of the concept in edible nut promotion.

CONCLUDING REMARKS

To fully meet expectations of pecan users implies recognition of multiple uses of pecans by households and food manufacturers. The multiple uses are reflected in different emphasis pecan buyers place on various attributes. Because pecan kernel attributes are influenced by genetic and environmental factors, the interdisciplinary cooperation becomes increasingly relevant approach for identifying and testing improvements in cultural practices, handling, shelling, storage, and use. Furthermore, such approach improves chances that developed knowledge will be quickly used by the industry.

Multiple uses of pecans imply various sets of expectations and create opportunities for market segmentation. The seemingly conflicting opinions suggesting the dychotomus distribution of pecan users' opinions need to be investigated to provide detailed profile of targeted segment of pecan users.

Although expectations are subject to change, assuring the users of steady supply of pecans of high quality will help promotion and advertising. The integrity of the product is necessary for a crop such as pecans because of the long productive life of trees, high removal costs, and the necessity to invest in machinery, equipment and irrigation in order to sustain economic viability of a pecan operation. The Pecan Industry must follow market developments and distinguish between short term food fads and the core preferences of pecan users mirrored in revealed expectations. The land-grant system scientists together with research personnel of the USDA-ARS will continue to develop new practical knowledge in this regard, while depending on close cooperation and support of the industry.

REFERENCES

Florkowski, W. J., E. E. Hubbard. 1997. Results of End User Survey. Proceedings of the 90th Annual Convention of the Southeastern Pecan Growers Association, Savannah, Georgia, March 1-3, 1997, pp. 108-115.

Table 1. Number of Years in Business

Years	Percent
5 or less	7.1
6 - 10	4.3
11 - 15	4.3
16 - 20	4.3
21 - 25	5.7
26 - 50	38.6
51 - 75	28.6
76 or more	7.1

Table 2. Value of Nuts the Company Dealt with in 1994

Category	Percent
Less than $250,000	18.7
$250,000 - $500,000	9.3
$500,001 - $1,000,000	10.7
Over $1,000,000/Less than $5,000,000	18.7
More than $5,000,000	42.7

Note: A total of 75 firms reported the value of nuts traded.

Table 3. Type of Company Ownership

Ownership type	Percent
Partnership	10.5
Corporation	75.0
Family business (not incorporated)	7.9
Cooperative	5.3
Other	1.3

Note: A total of 76 firms reported ownership type.

Table 4. Processing of Shelled Tree Nut Preferred by Buyers

Preferred type of processed nuts	Total sample	Number of respondents
	----------- percent -----------	
Whole nuts	75.6	45
Halves (whole not available)	88.4	43
Large pieces	82.2	45
Medium pieces	86.7	45
Small pieces	76.7	43
Meal	45.5	33

Note: A total of 78 firms responded to the survey

Table 5. Opinions about Statements Concerning Pecans

Statement	*Disagree*	*Somewhat agree*	*Agree*	*Strongly agree*	*Don't know*	*Number of respondents*	*No response*
	- - - - - - - -	- - - - - - - - -	percent -	- - - - - - - -	- - - - - - - -		
Intrinsic attributes							
High nutritional value	9.2	16.9	47.7	12.3	13.8	65	13
High fat content	4.5	14.9	43.3	25.4	11.9	67	11
Good tasting nut	0.0	4.5	28.8	66.7	0.0	66	12
Crunchy ingredient	4.5	16.7	40.9	36.4	1.5	66	12
Lifestyles							
For those of higher income	30.8	36.9	20.0	7.7	4.6	65	13
For modern people	28.8	31.8	21.2	3.0	15.2	66	12
For old-fashioned people	25.4	19.4	31.3	11.9	11.9	67	11
Market characteristics							
Specialty item	13.6	33.3	33.3	19.7	0.0	66	12
Well known nut	3.0	14.9	37.3	41.8	3.0	67	11
Utilization							
Many uses in baking	3.0	6.0	25.4	55.2	10.4	67	11
Traditional ice cream ingredient	1.5	7.5	35.8	46.3	9.0	67	11
Traditional snack	26.9	40.3	16.4	10.4	6.0	67	11
Cross nut comparisons							
Pecans taste better than other nuts	22.7	39.4	16.7	19.7	1.5	66	12
Expensive compared to other nuts	9.1	19.7	40.9	27.3	3.0	66	12

Note: A total of 78 participated in the survey.

THE EDIBLE NUT MARKET AND PRICE INFORMATION

Gellert Toth[1]

WHO IS THE FOOD INSTITUTE?

The Food Institute (FI) is a non-profit 501-c-6 trade association. It is governed by a board of trustees and supported by contributions of its members. The FI differs from other associations because it does not lobby or organize conventions or trade shows. Since the company does not accept advertising, it is considered an unbiased source of information.

Since 1928, the association has provided its members with timely, accurate and pertinent information. The Food Institute Report (FIR), published weekly on paper and "on-line," follows numerous food markets, including the pecan market.

SECTIONS OF THE FOOD INSTITUTE REPORT - HOW DO THEY RELATE TO THE PECAN MARKET

The three main sections of the FIR offer an update on what is new about competition, customers, governmental actions, and market developments. Each section deals with a distinct set of issues or reports.

The "Digest Section". This section provides information on industry trends, electronic retailing, retail outlets including supermarkets and changing consumer preferences, new product introductions, mergers and acquisitions, etc.

The "Digest Section" provides the following information pertaining to the pecan industry:

▯ New products containing pecans with the name and the phone number of the company introducing the product;
▯ Consumer trends and trends influencing nut consumption;
▯ Changes in consumers' perception of nuts and other food items; for example, the influence of health concerns, income level, age, gender, etc. on consumer nut purchase,
▯ Supermarket sales trends.

The FIR regularly compares the dollar value of supermarket sales and sale volumes of nuts to other food items. In addition, reports on new technology effecting the Pecan Industry are prepared. Reports on weather patterns effecting the Pecan Industry and the edible nut market broaden the information available to readers.

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[1] Senior industry analyst at the Food Institute, Fair Lawn, New Jersey.

The "Washington Section." This section informs about food product recalls, Federal Register Notices, changes in state and federal legislation regarding issues relevant to the food industry, news from government agencies including the U.S. Department of Agriculture (USDA), the Food and Drug Administration (FDA) and others, and precedent setting court cases.

The FIR contains pecan related information including recalls of all products containing pecans. In addition, news pertaining to the imports and exports of pecans are reported as they become available. A particularly important service provided by the FI has been closely following court cases involving Federal Marketing Orders.

The FI also offers a legal library on HACCP and food safety, Occupational Safety and Health Administration (OSHA) inspections, and food labeling issues. These reports are prepared and authored by the well known Washington D.C. based firm Olsson, Frank & Weeda, specializing in the food industry issues.

The "Market Section." The FIR may be best known for its "Market Section." The "Market Section" reports on numerous processed and commodity markets. The information is gathered from government and industry sources by a staff of industry analysts. A food industry analyst specializes in a group of commodities or food products and is an expert in a particular area, for example, edible nuts and nutmeats. The analyst has up-to-date information on market trends and conditions, production, pricing, etc. on all edible nut markets including pecans. The analyst is also able to provide historical information on edible nut markets for volume or price comparisons over time. The FI members have free access to this information although they charged a nominal research fee for the research of more complicated issues or questions. A large portion of the "Market Section" is devoted to the report titled "Nuts and Nutmeats." This section covers pecans, walnuts, pine nuts, cashews, Brazil nuts, almonds, pistachios, peanuts, coconut, hazelnuts, and macadamia nuts. On a weekly basis or as often as information becomes available, the report provides price and market information.

THE WEEKLY FOOD INSTITUTE REPORT'S PECAN SECTION

Cold Storage Holdings. The volume of in-shell and shelled pecans stored in cold storage in the U.S. is collected by USDA. A survey of all cold storage facilities is conducted by USDA officials, and when released becomes public information. Cold storage stocks are an important part of evaluating the market situation and the available supply. While cold storage holdings data greatly influences wholesale pricing, its importance could be altered by the way in which the industry interprets the data because it is uncertain what percentage of pecan cold storage stock is

saleable. A portion of cold storage stocks may already be contracted yet reported as cold storage in inventories. In addition, reports on overall quality of available supplies are not available. These gaps in information cannot be easily overcome without the industry cooperation.

Price Trends. The FI provides two years of price trends on a monthly basis to its on-line readers. The paper copy of the FRI compares current pricing with prices reported twelve months earlier. Five year price trends are published in the annual Food Markets in Review series. The FI could provide longer price series information to its members upon request.

Per Capita and Total Consumption. Consumption of pecans is closely correlated with wholesale pricing and available supplies. However, consumers' attitudes and preferences affect consumption in the long term. The yearly Food Markets in Review publication provides a ten-year series of pecan consumption data.

Import and Export Data. The FIR closely follows imports of pecans from major sources such as Mexico and minor producers, e.g., Australia. Imports, especially from Mexico, have been greatly influencing prices in the United States because the volume imported adds to domestically produced crop..

Production and Acreage Estimates. The FI reports on the subjective and objective estimates. The subjective estimates ae generated by the industry segments, while the objective estimates are provided by USDA. Furthermore, having access to historical data, the FI puts them in perspective by making comparisons to production data from prior years.

News on Foreign Production. Reports on production of edible nuts in major producing countries as well as market reports on countries consuming pecans such as Germany, Canada and the Netherlands are also published periodically. For many edible nuts, overseas markets represent important outlets and foreign demand can dramatically affect nut prices.

CROP ISSUES
The food industry analyst gathers information on the trade's perception regarding the overall quality of the crop or available supplies by contacting industry sources. Trade sources are constantly tracking crop situation, evaluating its outlook, and interpreting the observed events. Trade sources are capable of providing information about the new crop before official estimates are published. The speed with which the FI can communicate pertinent information to its members is important for making business decisions.

ANNUAL REPORTS

The January issue of the FIR contains a two-year price trend of each edible nut market including pecans. The FI also publishes its Food Markets In Review series on several markets including Nuts and Nutmeats. This publication covers five years of market trends, including price trends of several nut items; hence prices are easy to compare.

The FI reports prices of pecans for three grades: Fancy Halves and Pieces, Choice Halves and Pieces, and Standard Halves and Pieces. 'Fancy' refers to the highest quality product with the best kernel color. 'Choice', the second best grade is somewhat darker than 'Fancy ,' and 'Standard', the darkest color kernels, is the third best grade.

Pecan pieces are sized by screens while halves are evaluated by count per pound. Some of the most popular grades of pecans are expected to contain the following number of halves per pound:

Fancy Mammoth Halves	201-250 count per pound
Fancy Junior Mammoth Halves	251-300 count per pound
Fancy Jumbo Halves	301-350 count per pound
Fancy Large Halves	451-550 count per pound
Choice Medium Halves	551-650 count per pound

Pecan pieces, sized by screens, must meet the following requirements:

Fancy Extra Large Pieces through 36/64" over 32/64"
Fancy Large Pieces through 32/64"over 24/64"
Fancy Medium Pieces through 24/64" over 16/64"
Choice Medium Pieces through 24/64" over 16/64".

For simplicity, the FI regularly reports on Fancy Jumbo Halves and Choice Medium Halves as well as Fancy Large Pieces and Choice Medium Pieces. Price spreads between all grades exist, but are not reported due to technical reasons.

HOW THE DATA IS COMPILED?
A food industry analyst conducts a survey of the industry over the telephone. Among those surveyed are food brokers, suppliers, and buyers. Once the data on pricing and other issues are compiled, a summary report is prepared and published in the FIR. Respondents to the survey are assured of full confidentiality.

The National Pecan Shellers Association (NPSA) provided the FI a list of its members and offered cooperation and help in developing pricing and other market information. This working relationship benefitted the FI and the entire Pecan Industry because some NPSA members regularly contribute to the FIR.

Other sources/agencies used in developing accurate and useful statistics are:

□ U.S. Bureau of Census, which provides current and historical statistics on import and export data by country and commodity. For pecans inshell and shelled product imports are covered. The government uses the following harmonized codes for pecans: 0802901000 Pecans Inshell, and 0802901500 Pecans Shelled.
□ Economic Research Service-USDA supplies statistics on consumption of nuts including pecans. Production statistics, acreage information, crop estimates, etc. are also available.
□ Foreign Agricultural Service-USDA provides data on production and acreage in foreign countries. Also, focus presentations on markets of major nut consuming countries have been available.
□ Industry associations such as the NPSA and the Texas Pecan Growers Association provide production estimates which are independent of the USDA estimates.
□ Universities provide useful statistics on uses, utilization and distribution of edible nuts. The University of Georgia supplies most of this information on pecans.

The challenge in collecting pricing information on pecans and other edible nuts. Many domestically produced nut markets are two tiered. Prices offered by smaller companies are generally lower than their larger counterparts with a large market share. Smaller competitors are in a greater need of cash to purchase new crop or to repay loans accrued during harvest. Larger companies tend to have fewer problems with liquidity, hence are generally firmer on pricing.

The gap usually dissipates once stocks owned by smaller companies are sold. Also, during years of short crop, prices charged by small companies tend to increase at a faster rate and the gap is very small or non-existent. The FI has dealt with this problem by reporting price ranges rather than a single price for a specific grade.

The entire industry is effected by two tiered pricing which causes "softening" of prices at all levels of trade. Large companies claim that their profits are negatively impacted by this practice. Profits of smaller companies are also depressed because actual sales can take place at or below the processing costs. "Blow out" sales confuse the market leading end users to perceive 'bargain' prices as true market price levels. On numerous occasions, the FIR clarified such misunderstandings.

WHO USES THE INFORMATION COLLECTED?

The FI members include grocery retailers, grocery manufacturers, food service distributors, importers, exporters, schools/colleges, governments/associations, banks, brokerages, etc. Nearly 5,000 food industry executives in organizations in the United States and 40 foreign countries receive the FIR every week. Based on the FI survey, it is estimated that approximately 25,000 people read it every week. Some of the largest users and suppliers of pecans are among the FI members. Most large supermarket chains throughout the country are also members as is a significant number of confectioners, bakers, food service operators and wholesale distributors. These companies are important buyers of pecans.

The FI is determined to provide accurate, pertinent and timely information to its members. Such information will benefit the entire food industry as the increased amount of accurate information makes possible the making of educated decisions. The FI believes that through better decision making companies can and will become more profitable in the long run. The FI provides the tools that aid decision-making.

Agricultural Economics II
1:00 - 1:25 p.m. Tuesday June 23, 1998

Speaker: Scott Landgraf

NOTE: Scott introduced his wife Janice and established the base that he operated the orchard and that Janice operated the retail sales outlet. As such, Janice would be asked to help answer questions.

Question: What varieties are more in demand?

Answer: Janice - Mohawk, but as with most other varieties you must shake the trees hard at harvest. If we shake the trees hard and get most of the crop, we can dry the pecans and quality is generally excellent. Choctaw and Pawnee are two other popular varieties.

Question: Some small "mama/papa" direct sales outlets by a highway want to switch to a shelled product. The question is should they and what are some of the problems and constraints?

Answer: Yes they should. If they are thinking of going in that direction due to demand for these services, that should be the logical next step. Our operation has shifted in that direction. They should plan to shift in progressive steps - part next year, or maybe the year after that. Shifting to incorporate shelling facilities is a matter of controlling quality. By controlling the whole process, we can also control and assure quality. I would not recommend going into cold storage. We concentrate on servicing customers with a high quality fresh product on buying days only. Janice Landgraf: Ten years ago buyers would buy whole pecans in-shell and crack and shell their own. That demand has dwindled. With a 60 year plus age customers group, they want complete products. This means having cracked, shelled and even going as far as placing them (the pecans) in freezer bags. We concentrate on providing a customer service oriented product.

Question: Whether we (speaking collectively about the pecan industry) have a crop or not and the quantity and quality of that crop makes a big difference in the market place. How

do you decide to keep going, speed it up or slow it down?

Answer: Generally, we are not faced with those problems. With the exception of one year, when we froze out, we have not had trouble filling our quality standards from our own resources. So far, we have met our quality standards. That is to say that we do whatever it takes to assure quality, starting at the orchard ie., if it takes 24 hrs per day to irrigate, that is what we do. We know that our market will clear about $1.75-2.00/lb in-shell, so we gear our whole input scheme based on that profit potential.

Question: Do you mechanically thin as part of your quality control program?

Answer: Yes, the primary focus of our operation is quality since we depend strictly on customer referrals. We thin and do whatever else is necessary to control quality. In addition, one year not too many years ago, over-production by Mohawk was the cause of the death of trees. Death of trees got our attention very quickly. Dr. Smith's (Dr. Michael Smith, Hort. Dept., Oklahoma State) work in the area of thinning made our system work. Crop load management is an excellent tool to maintain the orchard, manage production and improve quality.

Question: What size orchard do you operate?

Answer: 170 acres irrigated and 160 acres dryland. The acres dryland are located in deep alluvials soils. Seventy of the irrigated acres are in the process of being re-planted to other crops. We will probably end up with 100 acres irrigated and 160 acres dryland. The key is proper nutrition, water and management. The orchard will produce.

Question: Small Alfalfa producers with 5-10 acre operations are looking for alternative crops. Is it possible to switch this 5-10 acre operations to a pecan orchard?

Answer: Its possible, but economies of scale play a big part. For example, a new sheller will cost $15,000 or more, a small building will cost $10,000 or more. The associated required equipment may make it very difficult for a small operation to operate efficiently.

In addition, developing a market becomes a real challenge. We moved to the direct market when the best we were offered, as a small orchard, was $0.65/lb. We worked hard to develop a market and now cover Ada Oklahoma, but ship all over the U.S., including Germany. We build on a referral customer relation system which works quite well for us. A new small grower would have to do all this, plus develop his production system. This may be possible by only very few individuals.

Question: Do you have limitations of the quantity i.e., the minimum and/or maximum purchasing quantities?

Answer: No limit. Whatever quantity from zero to however much quantity a customer wants. Our customers are free to roam the store and sample the pecans. We have trash bins throughout the store and actually encourage sampling. Very seldom does too much sampling become too costly. Its the cheapest form of advertizing that we have.

Question: Making cookies - What variety would you recommend on making cookies?

Answer: Janice: Don't use Mohawk. Maramec is a good variety. Most varieties lend themselves to making cookies.

Question: What about the Internet? Do you market through the Internet and/or plan to expand to that system?

Answer: No and that system is not a priority for now. Our customers base keep us busy. At this time we are satisfied with our customer base and feel that we do not need to expand to that and other marketing schemes. For example, as we travel throughout the country, I take Janice to other similar shops. We compare their products. I constantly suggest items to Janice which we may want to carry in our shop. Janice has come up with a good response: people come in (to our shop) with a certain amount of dollars to spend. What is our business - pecans or trinket sales. After this analysis we end up concluding that our business is pecan sales. That is what we know, can control and forms our base for our marketing plan.

Comments by Dr. Storey: On the way from El Paso to Ruidoso, we passed the Eagle Ranch retail outlet. This is a first class operation. They planted a pistachio orchard and now have expanded by adding a sales outlet where they carry pistachios plus trinkets.

Question: Are you going to build any storage facilities and expand your operation?

Answer: We concentrate on the fresh market. Our outlet operates only during the Nov.-Dec. period, coinciding with the harvest. If we decide to extend, the purpose of storage would be to extend our operation through the May-June period, which we are not willing to do at this time. At this time, we plan to continue to concentrate on the high quality fresh market. We focus on this high quality fresh market in our daily operations. For example, we don't crack pecans ahead of time. We focus on cracking them fresh. If someone buys pecans, we crack the pecans for them, if they want this service, at the time of purchase.

MANAGING THE PECAN NUT CASEBEARER

Bill Ree[1]

ABSTRACT

The pecan nut casebearer, *Acrobasis nuxvorella* Neunzig, has been considered one of the most important nut feeding insects of pecan for over 80 years (Bilsing 1926) and in Texas, insecticides will have to be applied in most years to prevent economic losses.

Proper management of this insect is based on monitoring oviposition and making treatment decisions on egg and larval density and crop load.

Current management tools for pecan producers include pheromone baited sticky traps and degree day models to detect and predict activity and a sampling model to assist with treatment decisions.

INTRODUCTION

The pecan nut casebearer (PNC), *A. nuxvorella* Neunzig is one of the most important nut feeding insects of pecan. The impact of this insect on a pecan crop can range from complete devastation with 80 to 100 percent crop loss, to beneficial where a light infestation can thin an over loaded crop. This wide range of crop impact presents producers with the dilemma of determining, each season and for each orchard, if, or when a treatment may or may not be needed.

To successfully manage PNC, producers need to be in the orchard, monitoring activity at the correct time so proper management decisions can be made.

To assist producers in making management decisions, several tools have been developed that predict or detect PNC activity. Although monitoring or detection methods are available to tell producers when to scout, management or treatment decisions can only be made by scouting for and determining PNC egg and larval density.

CURRENT RECOMMENDATIONS

The most recent development in casebearer management was the discovery of the PNC female produced sex pheromone (9E, 11Z)-hexadecadienal

[(9E,11Z)-16:Ald]. The pheromone was initially identified by Dr. Jocelyn Millar in 1993 (Millar et al. 1996). By 1996 the pheromone and a trapping system were commercially available for producers.

A trapping system using pheromone impregnated septas and sticky traps allows producers to monitor the onset of PNC adult activity.

Directions on pheromone trap usage are published in the Texas commercial insect control guide, B-1238 for pecans (Knutson and Ree, 1998) and in the Texas Extension Pecan Nut Casebearer Fact sheet, L-5134 (Knutson and Ree, 1998). The following information is provided to producers through these publications:

Pecan Nut Casebearer Pheromone Traps

1. Pheromone lures and traps are commonly sold together as kits. There are many different trap designs but kits sold for pecan nut casebearer use either the Pherocon 3 Delta trap, the Pherocon 1C wing trap, or the Intercept-A trap. All three trap designs are effective in determining the pattern of moth activity. Pheromone lures should be kept frozen until used. Lures should be replaced every 6-8 weeks and removed from the orchard and discarded.

2. Three pheromone traps are sufficient to determine the pattern of moth activity in a given location. As a general guide pending further research, consider 3-5 traps for orchards less than 50 acres in size and 5 or more traps for orchards larger than 50 acres. Additional trapping locations should be considered where orchard conditions vary such as between river bottom sites and upland sites.

3. Traps at a location should be separated by at least several trees. Place traps near the terminal of a nut-bearing limb at a convenient height. Traps placed in the lower canopy provide an accurate reflection of moth
activity. Although data indicate that traps placed at greater heights in the canopy capture more moths, the pattern of activity is the same and thus the extra effort to place traps high in the canopy is not rewarded.

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4. Place pheromone-baited traps in the orchard four weeks prior to the expected spray date. Traps must be in the orchard before the moth flight begins to be sure that the date of the first moth capture represents the beginning of moth activity. In south Texas, traps should be in the orchard by April 1, in central Texas by April 15 and in north Texas by May 1.

5. Traps should be monitored at least every 3-4 days and three times a week if possible. Frequent monitoring is necessary to detect the first flush of moth activity. Each time the trap is checked, the number of captured casebearer moths should be counted and recorded. The trap location and sample date should also be recorded. All moths, other insects and any leaves or twigs should be removed from the trap. Do not confuse pecan nut casebearer moths with pecan bud moths and other impostors which are sometimes captured in pheromone traps. Replace traps or trap liners when the sticky material becomes covered with moth scales, dust or other debris. Transfer the pheromone lure to the new trap or liner using forceps or the tip of a pocket knife blade to avoid contaminating the lure.

6.. Begin scouting the orchard for casebearer eggs 7-10 days after the first pecan nut casebearer moths are captured in the pheromone traps. The first casebearer male moths are typically captured two weeks before the optimum time to apply an insecticide. During this time, trap catches will typically increase and then begin to decline over a 2-3 week period. There may be a temptation to apply an insecticide during peak moth capture, but such an application would be a week or more before a properly timed treatment, if needed, should be applied. Current research indicates that numbers of captured moths accurately reflect patterns of moth activity. *Trap catches can not at this time be used to predict the threat of damage by casebearer larvae or the need to apply an insecticide.* For this reason, it is necessary to closely scout nutlets for eggs and nut entry to determine if a damaging infestation is present that will justify an insecticide application.

7. Pheromone traps can also be used to monitor flights of later casebearer generations. A second moth flight can be detected about 6 weeks after the spring flight and follows a similar pattern of increase and decline during a 2-3 week flight. Nut entry, and thus optimum timing of an insecticide application for second summer generation casebearer, *if needed,* will occur about 12-16 days after the second moth flight begins. As with the first summer generation, the decision to treat the orchard should be based on the presence of eggs and larvae and not the number of

moths captured. The pheromone trap is very attractive and will capture casebearer moths even when an economic infestation of larvae does not develop. Pheromone traps will continue to capture moths of the third and fourth generations throughout the summer into November. However, these later generations are rarely a threat to nut production.

There has been temptation by producers to treat for the adults or at the initial catch. Research has shown that the time from initial catch to nut entry is approximately 14 days. The time frame for population build up for the first summer generation is listed in table 1.

Degree Day and Sampling Models

Another method of monitoring PNC is with degree day models. Currently there are two models available to producers that predict development and activity of PNC. The Texas degree day model is a heat unit driven model that uses a base temperature of 3.3 C (38 F) and a start date of March 12 for College Station, Texas (Ring 1983). To calculate degree days using this model, daily high and low temperatures are averaged and a base temperature of 38 is subtracted. If the total degree days for a day is less than zero, then zero days are recorded for that day. A summary of degree day accumulations for the different life stages of PNC is listed in table 2.

Start dates for areas other than College Station can be determined from budbreak information or frost free days.

The important factor in using degree day calculations is determining the start date. For using the budbreak method, degree days are accumulated from 10 days prior to 50 percent budbreak. When using the frost free day method, a change of 1 day from March 12, for the start date is made for each 2.72 frost free days difference from 266 (frost free days for College Station, TX). For colder areas start dates are delayed and for warmer areas start dates are accelerated. Start dates should never be earlier than March 6.

To assist producers in making treatment decisions, a sampling model was developed that allows producers to make treatment, no treatment required decisions based on degree day accumulations and infested clusters (Harris et al 1988). The sampling model is most accurate when 1825 degree days have been accumulated. The sampling model is shown in figure 1.

Another model that was developed in Georgia, (Sparks 1995) is currently available. This model uses chilling hours and heat uints to predict nut entry.

Biological Control

Predators and parasites play an important role in the natural control of PNC. Twenty-eight species of parasites have now been identified from PNC (Gunasena 1988). Of the parasites associated with PNC, most research directed at managing PNC with augmentative releases have been with *Trichogramma* wasps which are egg parasites.

Research and tests using *Trichogramma* for controlling PNC were started in the 1930's (Spencer 1949). Although PNC eggs are parasitized by *Trichogramma* wasps, the augmentative release of this parasite have not been successful in managing PNC at an economic level.

Pecan nut casebearer eggs, larvae and pupae are also preyed upon by many species of insects and spiders. Predators such as lacewing larvae, minute pirate bugs, assassin bugs and spiders prey on eggs and exposed larvae. Although many species of predators and parasites are associated with PNC the augmenative releases of natural enemies have not been shown to prevent economic losses. Natural enemies can best be utilized by conserving their numbers through the judicious use of insecticides.

SUMMARY

The objective of an IPM based program is to apply an insecticide only when damaging populations exist. Through monitoring oviposition, insecticide treatments, when needed are applied as late as possible so that only one application will be used. However, in some years two applications will be needed if there is an extended egg lay.

To help monitor PNC egg development in an orchard, Texas producers are encouraged to flag infested clusters during scouting operations. Information such as egg stage (white, pink, hatched), bud feeding and nut entry can be recorded on the flag for future reference. Producers are also encouraged to scout even after an insecticide treatment is applied to check for late egg lay and effectiveness of the insecticide.

As PNC expands its distribution range, the management tools that have been discussed will have to be evaluated in news areas.

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Table 1. Events in the life history of pecan nut casebearer beginning with initial trap catch. (Harris et al. 1995).

Males emerge about 3 days before females	3
Females require about 3 days for mating before egg lay	3
Eggs require about 4 days before hatch	4
Larvae feed on buds for 2 days before nut entry	2
Population buildup requires 2-4 days	4

TOTAL:
Days from first males in trap to nut entry estimated at   12-16

Table 2. Degree day accumulations for the different life stages of the pecan nut casebearer at different percent levels of population development.

	Overwintering Generation		1st Summer Generation		
Percentile	Pupation	Emergence	Oviposition	Hatch	Nut Entry
1st obser	--------	1350.3	1440.42	1680.9	1733.3
1st significate	--------	------	-------	-----	1831.1
10	955.9	1521.1	1822.5	1877.2	1908.8
25	1057.0	1631.0	1915.5	1008.7	2100.2
50	1183.0	1740.3	1932.5	2062.1	2136.1
75	1311.5	1865.1	1978.0	2274.0	2368.3
90	1413.0	1940.6	2146.0	2365.4	2610.3
Last Observed	1733.5	2140.9	2420.8	2450.7	2610.3

Figure 1. Sampling model for making treatment, no treatment decisions for first generation pecan nut casebearer. First sample should be taken at 1730-1760 DD. Inspect 10 clusters on each of 31 trees.

HICKORY SHUCKWORM IPM: PAST, PRESENT, AND FUTURE

John R. McVay[1]

ABSTRACT

Control of the hickory shuckworm, *Cydia caryana* (Fitch), has been approached in various ways since the widespread adoption of sprayer usage in commercial pecans. Methods have ranged from ignoring the pest to multiple applications of preventative insecticides. The inception of organized IPM efforts in the late 1970's directed more attention to the pest as an individual entity. Monitoring efforts have made application timing more precise and preventative sprays have become artifacts in most producing states. IPM efforts have been somewhat hampered by the required use of broad-spectrum insecticides which affected beneficial insect populations, often requiring follow-up sprays for secondary pests. The advent of target-specific pesticides that are less damaging to beneficial organisms and less disruptive to the orchard ecosystem bode well for the future of Pecan IPM and hickory shuckworm control.

INTRODUCTION

The hickory shuckworm, *Cydia caryana* (Fitch), is a key pest of pecan throughout the production areas of the United States (Osburn et al. 1963, Payne et al. 1979) and has been reported to rank as the most important pest in six southeastern states (McQueen, 1973). Damage assessment is difficult but losses due to damage and control costs have been estimated as high as $11.3 million annually in Georgia (Suber and Todd 1980). A multivoltine lepidopterous pest, there are four or five generations per year in most of the principal production regions. IPM efforts have been developed over the past 30 years with varying results.

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PRE-IPM CONTROL EFFORTS

Following the widespread adoption of orchard sprayer use by producers in the early 1960's, control of the hickory shuckworm along with other arthropod pests was achieved by the addition of broad-spectrum insecticides to calendar driven spray schedules. These spray schedules were keyed to the crop development phenology and called for chemical applications on a regular basis, normally a three week schedule (Phillips et al. 1960, Polles and Payne 1974). This approach to control was effective until the mid-1970's. During that time period, it became apparent that, although control of major direct pests such as the shuckworm was obtained, the effects of such liberal applications of broad-spectrum material on the orchard ecosystem was detrimental to naturally occurring arthropods that exerted control influence on secondary and occasional pests such as aphids, mites, leafminers and others. The result was large population increases of many of those pests, elevating them to primary importance.

This method of saturating the orchard with insecticides at regular intervals, with a variety of compounds, was effective in controlling generation two and three of the hickory shuckworm but was less so for the most damaging generation four. This stems from reliance upon Carbaryl, applied for control of the pecan weevil, for a suppressive effect on shuckworm populations during the critical fourth generation. Accordingly, less control of shuckworm was achieved and producers were forced to believe that an infestation rate of shucks at harvest was not of economical importance unless it was greater than twenty-five percent.

CONTROL UNDER IPM SYSTEMS; 1976 TO THE PRESENT

Organized efforts to implement Pecan IPM programs began in Alabama in 1976, followed immediately by Georgia and Texas (McVay et al. 1978, McVay and Ellis 1979). These programs were driven by systems of arthropod monitoring developed for each specific major pest and some secondary pests. Due to the difficulty of post-ovipositional control of immature forms, most programs have encouraged the monitoring of adult populations of the shuckworm. Monitoring procedures were based primarily on the use of blacklight traps suspended in the tree canopy and control applications were triggered by the numbers of adult moths of either sex captured during

specific time periods (Smith and Tedders 1978, Tedders and Edwards 1970).

This approach could be and was effective, especially in orchards with large endemic populations of the shuckworm in which treatments applied at peak activity periods throughout the season substantially reduced those populations over time. The major drawback of this system was a reluctance on the part of the producer to regularly monitor the traps, sorting through the large numbers of insects attracted to the traps and picking out the relatively small moths of the shuckworm. The most effective means of operating the trap was on alternating current which required an electric outlet in or near the orchard and constant maintenance. Attempts to control the shuckworm by placing traps in the orchard at the rate of two per acre were effective but were abandoned for the same reasons. Still, many producers did adopt this survey method and became proficient at identifying the moth and making control decisions based on captures.

In recent years, some Extension program specialists have established blacklight monitoring sites in orchards throughout their state's production region and provide producers with regular updates on shuckworm activity via toll-free telephone "hotlines" which the producers can call at any time. The positive aspect of this method is that producers have ready access to moth flight activity information but a negative is that unless their orchard is one that is equipped with a regularly monitored blacklight trap, they don't really know the activity level for their particular case and usually proceed on the basis of orchard history and crop load for the particular year.

In the mid-1980's, Smith et al, developed and released a synthesized sex pheromone of the hickory shuckworm. This type of attractant combined with easy to use traps has historically provided great benefit to various IPM programs. While initially very promising as a tool for directly monitoring shuckworm populations and activity patterns, the results of actual use have been mixed and particularly disappointing in the southeastern production region. Pheromone trap usage in the western production regions and in Mexico appears to allow producers to make control decisions on a timely and accurate basis. However, in the Southeast, only the first and last moth flights of the season appear to be monitored with any degree of accuracy with this tool (McVay et al. 1995).

The reason(s) for this difference in efficacy are presently unknown but some theories have been proposed. It is possible, but not extremely likely, that the pheromone was developed through research on a western strain of the species that produces a sex attractant slightly dissimilar to an eastern strain common to the southeast. However, this is somewhat discounted by the extremely high numbers of adult males attracted to the pheromone during the first and last flights of the season.

Possibly, a more plausible explanation lies in the habits of the insect itself and the occurrence of alternate hosts in the respective areas of production. In the Southeast, the moths of the first generation are known to move primarily to hickory which sets fruit earlier than pecan, which is not a particularly good host at the time of spring emergence. Therefore, it is likely that damage in pecan orchards due to generations 2, 3, and 4, is caused primarily by progeny of previously-mated migrants entering from nearby foci in native hickories. It has been shown that the majority of adult moths captured in blacklight traps during the time of the season in which these generations are active are gravid females and the majority of both sexes captured had been previously mated (Tedders and Edwards 1972). As wild hickory hosts are common in the vicinity of most shuckworm infested orchards in the Southeast and much less so in the far-western and Mexican production areas, a great deal of the difference in pheromone trap performance might be explained in this manner.

This is supported by the slight increase in activity detection by pheromone traps commonly found with each succeeding generation in the Southeast. As the second generation occurs, in the orchard, pheromone traps indicate very little activity. The damage to the crop at this time consists of larval feeding on very small, immature fruit, causing them to drop from the tree. Due to the fruit size, it is commonly accepted that only a small percentage of larvae are able to obtain enough nutrition to survive to adulthood, the so-called suicide generation. The damage caused by generation 3 in mid-July is similar to that of generation 2, but fruit size is considerably larger, allowing a larger percentage of larvae to complete development. Therefore a few more unmated males manage to develop within the orchard from this generation. Larvae of the critical fourth generation, which occurs during kernel fill and development can, in theory, all complete development to adulthood. The development of a large number of

adults within the orchard by this generation would explain the sudden increase in pheromone trap capture efficacy during the flight of fifth generation moths. Additionally, it is the progeny of the fifth generation that overwinters in the orchard , providing the moths of generation 1 that are readily attracted to the sex pheromone the following spring.

The net result is two methods of adult shuckworm monitoring, neither of which is close to a perfect solution for a well defined IPM program, but both of which have their uses in some areas of production. In the far-western production areas, the sex pheromone trap can be extremely useful, while in the Southeast, the blacklight trap has proven to be most efficient, despite its more cumbersome maintenance requirements.

Possibly the greatest impediment to the overall IPM effort in pecans as related to the hickory shuckworm has been the necessity of making control applications with broad- or, at best, relatively broad-spectrum insecticides and the resulting negative effects on the orchard ecosystem itself. All of the currently registered insecticides effective against and widely used for shuckworm control are deleterious to the large complex of beneficial arthropods commonly present in the orchard to some degree. The use of these materials to combat the destructiveness of shuckworm populations is necessary but often results in the elimination of or drastic reduction of natural control for secondary and occasional pests in the orchard. Primary among these are two yellow aphid species, *Monellia caryella* (Fitch) and *Monelliopsis pecanis* Bissell; the black pecan aphid, *Melanocallis caryaefoliae* (Davis); and the pecan leaf scorch mite, *Eotetranychus hicoriae* (McGregor).

It is common for populations of any or all of these secondary pest species to expand to destructive levels following applications of broad-spectrum organophosphate materials or synthetic pyrethroids for shuckworm control. This results in the producer making additional applications of various insecticides to control foliage feeding secondary pests that would quite likely have been controlled or at least suppressed below treatable population levels by natural enemies. This approach naturally results in somewhat of a continuation, although to a lesser extent than a calendar spray schedule, of the pesticide application merry-go-round that IPM programs are inherently designed to avoid.

FUTURE IPM POSSIBILITIES INCLUDING RESEARCH NEEDS

Despite the problems already discussed, management of the hickory shuckworm in an IPM context, has already progressed greatly from its point of origin. Recent developments in the agri-chemical industry and the aggressive research of scientists already at work in the pecan IPM area can only strengthen and improve the present situation. The agri-chemical industry has made great strides in identifying and developing new classes of reduced-risk pesticides that fit IPM strategies and hold great promise for future programs that can result in better crops produced in a more environmentally friendly manner. Although pecan production needs have historically been afforded a lesser degree of attention in the development of new chemistries and registrations than such widely grown high-value crops as cotton, the registration process for these new reduced-risk materials is being streamlined and they should come on line much more quickly for pecan IPM use.

These new reduced-risk or biorational pesticides have many qualities heretofore lacking in the pecan IPM arsenal. To varying degrees, they are less toxic to mammals and birds, are much safer to apply and most are target specific to certain insect or mite groups, whether affecting species of the same insect order or different taxonomic groups with similar feeding habits. At the time of this writing, one of the insecticides that is considered to have these qualities has been registered for use in commercial pecan orchards. That material is imidacloprid, sold under the trade names of Provado® and Admire®. This material is not active against hickory shuckworm but is simply the first of the new chemistries to be approved for pecan use.

Hickory shuckworm IPM will rely heavily on the reduced-risk materials in the future. Tebufenozide, marketed as Confirm®, is the first of several materials with similar properties currently being researched, to near registration. Tebufenozide is an IPM friendly material with low toxicity and has proven excellent for control of several lepidopterous pests in the pecan orchard. A mimic of the natural insect molting hormone, 20-hydroxyecdysone, this material induces premature construction of a new cuticle below the old, and the larvae starve to death due to an inability to shed the old cuticle. The effects f this material ppears to be confine

primarily to lepidopterous species and no effect has been shown on the complex of beneficial arthropods found in the pecan orchard ecosystem. Recent research has indicated that the use of tebufenozide for control of hickory shuckworm will produce excellent results without affecting the beneficial arthropod complex (author's unpublished data). This will allow chemical control to be applied for shuckworm populations without the necessity of follow-up insecticide applications aimed at secondary foliage feeders. The novel mode of action of this material also will make it an important tool in resistance management, due to little chance of cross resistance with other insecticides. The imminent registration of Confirm® and several other candidate, reduced-risk materials with similar properties will greatly enhance pecan IPM efforts. As these new control tools come on line to hopefully solve part of the shuckworm IPM equation, it is imperative that research be continued on the basic biology of this insect pest in an effort to optimize monitoring methodology. The author submits that it should be possible to develop an effective shuckworm lure based on insect attractant technology combined with pheromone-type traps to effectively monitor populations of the shuckworm in order to allow control decisions to be made based on insect activity and threat to the crop.

Although the sex pheromone lure has not proven to be the optimal monitoring tool it was hoped to be, its use in research has shed some light on the shuckworm's reaction to natural attractants. It has been observed that the placement of a trap charged with a sex pheromone lure into the canopy of a pecan tree will not simply begin to attract adult males to the trap. If there is little or no crop present in the tree, few shuckworm adults will be captured; conversely, if a good crop is present more adults will be present and will be caught in the trap (author's unpublished data). It is obvious to anyone who has noticed the above trend, that there is a karimone attractant associated with the presence of fruit much more powerful than that of the sex attractant. The moths are attracted first to a pecan tree with a crop load, and once within the canopy of the tree, to the less powerful sex pheromone. Accordingly, a biochemical assay of volatiles associated with the immature pecan fruit could possibly yield an attractant that could be synthesized and used with pheromone-type traps to effectively monitor both populations and damage potential of the hickory shuckworm.

Much progress has been made in development of IPM methods for dealing with the hickory shuckworm as part of the overall pecan management effort over the previous twenty years. However, the author feels that we are only now on the threshold of the technology that will allow development of a true Pecan IPM program.

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MANAGING KERNEL FEEDING HEMIPTERANS IN PECAN

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Additional Index Words. Pentatomidae, Coreidae, *Nezara viridula, Acrosternum hilare, Euschistus servus, Euschistus tristigmus*, trap crop.

The primary insect pest species attacking pecan, *Carya illinoensis*, across the U.S. pecan belt include the pecan weevil, *Curculio caryae*, pecan nut casebearer, *Acrobasis nuxvorella*, hickory shuckworm, *Cydia caryana*, three aphid species including blackmargined aphid, *Monellia caryella*, yellow pecan aphid, *Monelliopsis pecanis*, and black pecan aphid, *Melanocallis caryaefoliae*, and several phylloxeran species including pecan leaf phylloxera, *Phylloxera notabilis*, southern pecan leaf phylloxera, *Phylloxera russelae*, and pecan phylloxera, *Phylloxera devastratrix*, as well as a complex of kernel feeding hemipterans.

The pecan nut casebearer and the hickory shuckworm are generally considered the most damaging pecan pests west and east of the Mississippi River, respectively. In the Mississippi Delta, however, the pecan weevil is not known to occur, the pecan nut casebearer is only an occasional pest, the hickory shuckworm is managed by removing alternate hosts and disposing of shucks at harvest, and pecan aphids are generally held in check by natural enemies which are enhanced by the use of cover crops. Therefore, the kernel feeding hemipterans are considered the most damaging pecan pests in the Mississippi Delta.

Recent IPM developments within several host crops of these hemipterans include the pecan nut casebearer pheromone lure, several pecan weevil monitoring traps (i.e. Tedders trap) and Bt cotton. Along with the increased acreage of corn, which is generally considered a low insecticide input crop, these new tools have contributed to an overall reduction in insecticide use across wide acreage within the pecan belt. Collectively, this reduced insecticide load has shown evidence for increasing the incidence of pests which are generally considered to be secondary, including these hemipterans. Therefore, the kernel feeding hemipterans have the potential to become the primary pest complex in pecan across the pecan belt.

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The kernel feeding hemipterans include a group of phytophagous pentatomids: the southern green stink bug, *Nezara viridula* (L.), the green stink bug, *Acrosternum hilare* (Say), the brown stink bug, *Euschistus servus* (Say), and the dusky stink bug, *Euschistus tristigmus* (Say), as well as *Oebalus pugnax* (F.), *Banasa dimidiata* (Say), *Brochymena* spp. and *Hymenarcys nervosa* (Say), and a group of phytophagous coreids (leaf-footed bugs), including: *Leptoglossus phyllopus* (L.), *L. oppositus* (Say), *Acanthocephala* spp., and *Anasa armigera* (Say) (Dutcher and Todd 1983). Feeding by these insects results in two types of damage to pecan fruit. The first type of feeding damage, known as black pit, is caused by feeding on the nut during the "water stage" (prior to shell hardening). This feeding may result in premature nut drop, and often causes the nut interior to discolor and the shuck to adhere tightly to the nut. The second type of damage, known as kernel spot, is caused by feeding on the nut after the kernel has formed and entered the "dough stage" (after shell hardening). This feeding results in localized black circular lesions on the kernel surface that are not detectable until after harvest when the nuts are shelled (Demaree 1922, Turner 1923). These spots lower kernel quality and can also result in a bitter taste (Demaree 1922, Turner 1923). Furthermore, it is important to note that hemipterans are known to feed on pecans prior to, during and following pecan harvest, or in other words, while nuts are on the tree, on the ground or in unprotected storage, respectively. Collectively, black pit and kernel spot reduce yields and nut quality, and therefore, net profits to pecan growers.

Utilizing several sampling methods (black-light and malaise traps, D-Vac, and direct hand-sampling of the tree crown), Dutcher and Todd (1983) found that *N. viridula* and *E. servus* were present during the entire season and overwinter in the orchard. Demaree (1922) noted that these pest species migrate into pecan orchards throughout the growing season, but appear to be particularly abundant in September and October. Control of these kernel feeding hemipterans is currently based solely upon the use of insecticides. However, several very important problems are associated with the use of insecticides for control of this complex. First, there are currently no reliable methods available for monitoring hemipteran movement into nor within pecan orchards, thereby making it difficult for growers to determine when to intensify scouting efforts for hemipterans. Secondly, there are no treatment thresholds for hemipterans

within pecan, thereby making it difficult for growers to determine if population levels within the orchard warrant insecticide application. Finally, because it is unlawful to apply the currently registered insecticides after shuck split, when hemipterans are known to continue to cause severe kernel spot damage, development of alternative approaches to insecticides are essential for management of this potentially devastating pest complex.

MIGRATION: SOURCE & TIMING

The pecan weevil, pecan nut casebearer, hickory shuckworm, aphids and phylloxerans are all highly host specific and restricted to pecan or a few closely related *Carya* species. In stark contrast, the kernel feeding hemipterans are polyphagous, feeding on a wide variety of wild and cultivated host plants. Some of these hemipteran host plants include, bean, cowpea, squash, tomato, peach, okra, soybean, pepper, cotton, corn, mesquite and cockelbur (Turner 1923; Adair 1932). Although they appear to be polyphagous at first glance, they are actually sequentially monophagous, whereby they migrate from crop to crop within a given season based upon the phenological stage of development of their preferred host plants. For example, during the past five years we have determined that hemipterans increase in number over the course of the growing season primarily in soybeans (source crop) in the Mississippi Delta, but may also build in corn and cotton (Smith 1996, 1997, 1998). We have further determined that the majority of hemipterans migrate out of soybeans and into pecan orchards from approximately seven days prior to and through soybean harvest. While the source crops may vary from area to area, hemipteran migration should coincide with the windows of time during which the source crops have developed beyond the stage preferred by the hemipteran species. Therefore, identification of the source crops of hemipterans within a given area, together with knowledge of their respective developmental phenologies, should provide growers with a predictive measure of hemipteran migration to pecan.

TRAP CROPPING: PLANT ATTRIBUTES

In addition to knowing the origin of the hemipterans entering pecan orchards and the mechanisms which might trigger such migrations, there are at least two additional critical challenges faced by pecan growers regarding hemipterans. First, pecans tend to be the terminal crop for hemipterans. In other words, pecans are attacked: (a) after hemipterans have developed

through several generations over the season on preferred hosts (source crops), (b) after pecan growers have invested the majority of their annual production costs (i.e. associated with disease and insect control) and (c) when few if any other suitable cultivated host plants are available. Secondly, hemipteran populations and the resulting kernel spot levels sustained within a pecan orchard are significantly influenced by crop management decisions implemented by farmers growing crops in and around the pecan orchard, regardless of the management decisions and resulting costs incurred by the pecan grower. Therefore, the polyphagous nature of kernel feeding hemipterans and their highly migratory behavior, requires that their management be viewed at a broad landscape level. One such deliberate alteration in pecan production which views hemipteran management at the landscape level is trap cropping. Trap crops are defined as plants grown to attract insects in order to protect a target crop (pecan in this case) from insect attack. Trap cropping is based upon the principle that all pests show a distinct preference for certain plant species, cultivars or stages of crop development. The objectives of trap cropping in pecan IPM are to intercept hemipterans as they migrate into pecan orchards, and to concentrate them within the trap crop where they can be effectively and economically controlled. Some of the potential benefits of trap cropping include reduced insecticide use and therefore reduced environmental and health risks, conservation of natural enemies of pecan aphids and therefore reduced risk of late season aphid outbreaks, and reduced input costs and therefore greater net profits.

Since 1992 we have been conducting research in an effort to identify plants that meet the essential criteria of an effective trap crop (Smith 1996, 1997, 1998). The attributes investigated have included: (1) attractiveness to the key hemipteran species; (2) phenological synchronicity with hemipteran migration into pecan (August through pecan harvest); (3) ease of culturing; and (4) drought and cold tolerance. To date, several indeterminate pea varieties, speckled purple hull pea and zipper cream pea, have been found to be attractive to *E. servus, E. tristigmus, A. hilare* and *N. viridula*. These two pea varieties, when planted from May through early June, are synchronized with the senescence and harvest of soybeans, specifically Maturity Groups IV and V, and the subsequent hemipteran migration into pecan. Furthermore, these indeterminate peas are easy to culture, requiring only a single planting when moisture is normally adequate for germination. Pinkeye purple hull pea, a determinate variety, is not a suitable trap crop because

it requires two to three plantings, particularly during mid to late summer when adequate moisture is seldom available for germination. In addition, a study conducted during 1997 showed that determinate soybeans, specifically late maturing beans (i.e. Maturity Groups VII, VIII, IX), are more tolerant of the cool temperatures that are commonly experienced prior to pecan harvest than are the indeterminate peas. Therefore, a mixture of several indeterminate peas (which intercept the majority of immigrating hemipterans), and determinate late season soybeans (which intercept late season immigrants), may be envisioned as the preferred trap cropping system. However, while the trap crop plants identified to date are attractive to each of the key hemipteran pest species, particularly *E. servus, E. tristigmus, A. hilare* and *N. viridula*, evaluation of the attractiveness of these plants relative to various pecan cultivars is essential in order to insure that the hemipterans preferentially migrate to and remain within the trap crop.

TRAP CROPPING: INSECTICIDAL CONTROL

A trap crop has the undesirable distinction of potentially serving as a breeding ground for hemipterans, thereby allowing them to increase in number and move into the orchard. Therefore, it is essential that the hemipterans be directly controlled within the trap crop. Although based upon few comparative experiments, the results from our trap cropping studies suggest that timing of insecticide applications for control of hemipterans should be based upon two criteria: (1) senescence of the soybeans or other source crops adjacent to or in close proximity to the pecan orchard; and (2) weekly or biweekly sampling of hemipterans within the trap crop, at least during senescence and harvest of the surrounding source crops. Both the number of immigrating adult hemipterans flying into the trap crop, as well as the proportion of late instar nymphs (F1's), should be considered in making a spray decision. More simply stated, from the initiation of source crop senescence through harvest, when adult hemipterans are found within the trap crop, or when their offspring begin to reach a relatively high proportion of the total hemipteran populations, a spray decision should be made. Furthermore, prior to shuck split, while insecticides can be legally applied within the pecan orchard, sprays should be applied to both the trap crop and at least the border trees within the orchard. After shuck split, when insecticides can no long be legally applied within the orchard, applications should be confined to the trap crop. Hand sprayers, high-boys

and aerial application are all options for applying insecticides to the trap crop. Aerial application appears to be a cost effective and efficient alternative to air blast type sprayers for use within the orchard. However, more definitive quantitative studies on sampling, treatment thresholds and application methods are needed.

TRAP CROPPING: FACTORS AFFECTING EFFICACY

A number of factors may influence the efficacy of trap cropping as a method for controlling hemipterans within pecan orchards. In addition to the factors discussed above (trap crop plant attributes and insecticide control strategies), hemipteran population level and species, and the hemipteran attractiveness to pecan cultivars relative to the trap crop plants and/or their respective phenologies, represent additional factors.

A three year investigation of feeding preference among Desirable and Stuart pecan was recently completed (Smith 1997, in review). Based upon 5 preference indicators (percent nuts and kernel halves with kernel spot lesions, numbers of lesions per nut and kernel, and the percentage of nuts where both kernels contained kernel spot), this study provided the first reported evidence of hemipteran preference for Desirable over Stuart pecan. Ranking these preference indicators suggested that the number of lesions among all nuts or kernels was a more consistent indicator of hemipteran cultivar preference. Furthermore, kernel spot lesions per damaged nut and kernel indicated that once hemipterans select a cultivar on which to feed, there are fewer probing and feeding events on individual Stuart nuts than on Desirable nuts. Although identification of the hemipteran species responsible for the damage in this study was not known, *E. servus* was the dominant species, followed by *A. hilare* and *N. viridula*, in samples collected along the orchard margin. Potential mechanisms of cultivar preference and feeding behavior among the kernel feeding hemipterans were discussed.

Results from a more recent caging study of hemipteran preference among 15 pecan cultivars indicated that, overall, *E. servus* causes greater numbers of kernel spot lesions than *A. hilare*, and that females of both species cause more kernel spot lesions than do males (Smith, unpublished). While the results also indicated a differential cultivar preference among these two hemipteran species, additional analyses are needed. In particular, the nut characteristics responsible for the

observed preference should be elucidated. These include shuck and shell thickness, nut phenology and shell hardness. Results from the recent investigations indicate a differential shell and shuck thickness among cultivars, but correlation among these nut characteristics and feeding preference has not as yet been determined.

CONCLUSIONS

The kernel feeding hemipterans are considered to be the most damaging pecan pests in the Mississippi Delta. However, when coupled with the reduced spray schedules for the pecan nut casebearer and the pecan weevil as a result of recently developed IPM tools, and the reduced spray schedules in Bt cotton and corn, hemipterans have the potential to become the most damaging pecan pests across the pecan belt.

Polyphagy requires that IPM be viewed at the landscape level because management decisions which are beyond the pecan growers control, in large part, dictate the hemipteran species composition, population level, and timing of migration to their orchards. Furthermore, sequential monophagy may actually be advantageous to the pecan grower, given that the host preference hierarchy of the hemipteran species are known. Therefore, identification of the source crops of hemipterans within a given area, together with knowledge of their respective developmental phenologies, should provide growers with a predictive measure of hemipteran migration to pecan. This would also provide scientists and extension agents with a predictive model of hemipteran migration, whose inputs could be readily modified to adequately reflect local site specific cropping systems and phenologies.

The distance that hemipterans fly in order to locate suitable food has not been documented. Once determined, this knowledge would be indirectly incorporated into the model so as to define the appropriate spatial dimensions of the landscape in which a specific grower is operating. Ultimately, the hemipteran preference among trap crop plants relative to specific pecan cultivars, as a function of their respective phenologies, will be vitally important to the use of trap cropping. This knowledge will allow growers to select a bouquet of trap crop plants from among a trap crop plant menu which will meet their local source crop and pecan cultivar situation.

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PECAN IPM PROGRAM APPROACHES: PAST, PRESENT AND FUTURE

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ABSTRACT

Organized IPM programs for pecans were first established in 1976. Since that time, programs have made much progress in dealing with pests with individual, systematic approaches. Pest problems and methods vary from region to region and state to state within regions. The largest obstacle to true IPM has been a lack of target specific pesticides and difficulties monitoring two of the most damaging fruit pest species. Some of these continuing problems appear close to resolution and future efforts are expected to continue improvement of the overall programs.

INTRODUCTION

The development and implementation of effective Insect Pest Management systems for commercial pecan production is a complicated matter. The pecan is a crop native to the U. S. and all major arthropod pest species that affect its production are native as well. As a result of untold years of co-evolution, the arthropods that utilize the pecan for survival occupy specific niches that complicate efforts at population monitoring, control decision making, and control mechanisms, especially any attempt at natural or biological control. As example, it is not feasible to import and release beneficial organisms effective as pecan arthropod control agents with few exceptions. Thus, most pecan IPM program efforts have been forced to concentrate on development of pest monitoring programs which provide pest population data which is then used to trigger artificial control measures. This paper will attempt to briefly describe the arthropod control and management efforts during the last half of the current century.

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PRE-IPM EFFORTS: 1960 THROUGH 1976

With the introduction of the airblast orchard sprayer pecan producers quickly began to make maximum use of synthetic pesticides to replace earlier attempts at cultural control of pest species. The various Extension Services responded by evaluating any new pesticide available for orchard use and developing spray guides for growers. These guides were based on crop phenology and normally called for ten to fifteen chemical pesticide applications throughout the growing season, usually tank mixes of fungicides and insecticides with occasional additions of nutrients (Osborn et al. 1963).

This preventative technique of pest control was effective, especially for control of the major fruit feeding pests, for several years. In the early 1970's, however, it became apparent that pecan culture was following the classic pathway to problems due to over-reliance on chemical pest control common to many crops. The majority of orchards had breezed through the exploitation phase of pest management development and were edging into the crisis phase (Metcalf and Luckmann, 1982). It was becoming more difficult of control the known major pests without the use of newer, more toxic and more expensive chemistries. Additionally, pests that had heretofore been considered of little economic importance as secondary or occasional pests were appearing in ever increasing numbers, causing widespread damage and continually increasing costs of control measures. It became apparent to both scientists and producers that a change in tactics was necessary.

DEVELOPMENT OF IPM PROGRAMS: 1976 TO THE PRESENT

Following intensive research into pecan IPM possibilities for individual pests or pest complexes during the early 1970's, the first organized integrated programs were begun in Alabama, Georgia and Texas in 1976 and 1977 (McVay et al. 1978, McVay and Ellis 1979, Payne 1983). These programs, individually and in concert, began to develop systems for monitoring each specific major arthropod pest as well as several secondary pests that had been elevated to primary status due to pesticide overuse. Due to the variety of pest types present in the orchard ecosystem, development of both absolute and relative sampling methods (Ruesink and Kogan, 1982) were required to provide adequate population estimates in order for control decisions to be made.

Specifically designed trapping systems were developed for some pests (Smith and Tedders, 1978), while other studies concentrated on developing the types of samples and samples sizes needed for proper control decisions. Table 1 lists the key arthropods for which population monitoring methodology was developed.

Table 1. Arthropod Pests Sampled in Initial Pecan IPM Programs

PEST	FEEDING SITE	TYPE OF SAMPLE
Pecan Weevil, *Curculio caryae*	Maturing fruit (nuts) prior to harvest	Various emergence traps
Pecan Nut Casebearer, *Acrobasis nuxvorella*	Immature fruit during pollination period	Incidence of eggs, larvae or damage in fruit clusters
Hickory Shuckworm, *Cydia caryana*	Within immature fruit prior to shell hardening, in shuck thereafter	Trapping of adults by blacklight traps
Yellow Aphid Complex, *Monellia caryella*, *Monelliopsis pecanis*	Foliage	Direct count of aphids present on a specific number of compound leaves per tree
Black Pecan Aphid, *Melanocallis caryaefoliae*	Foliage	Direct count of aphids present on leaves plus damage lesions
Pecan Leaf Scorch Mite, *Eotetranychus hicoriae*	Foliage	Direct count of mites active in sample area of leaflets and estimation of damage levels
Pecan and Alder Spittlebugs, *Clastoptera achatina*, *C. obtusa*	Growing terminals and fruit clusters	Incidence of terminals infested

Pecan weevil (PW). Recognized as the most destructive insect pest of pecans nationally, the pecan weevil has proven to be extremely difficult to sample and almost impossible to manage without foliar applications of insecticides. Due to the difficulty of post-ovipositional control of immature forms, programs have been developed around the monitoring of adult populations as they emerge from the soil and move to the tree for feeding, mating, and oviposition (McVay and Ellis, 1979). Various techniques have been used to monitor emergence and movement of the adults; burlap sacking or rubber tubing around the trunk, sticky substances on the trunk, knockdown sprays applied to indicator trees, limb jarring, and various types of emergence traps placed under the dripline of trees with proven infestations. All of these method have proven workable to some degree with the most widely adopted being cone emergence traps, and most recently the "Tedder's" pecan weevil trap (Tedders and Wood, 1994), sometimes used in conjunction with knockdown sprays in a few trees.

Traps are placed in the orchard during mid-July, and checked periodically until the first adults are detected. The traps are then observed daily for signs of sudden increases in emergence with monitoring continuing until emergence ceases, usually in late September. No threshold number of adults captured is used in most IPM programs. The standard guidelines in most states is to treat *after the kernels gel and the shells harden, whenever emergence increases, and/or following rains during emergence periods, continuing treatments at 7 to 10 day intervals until emergence ceases* (Ellis, 1989). Boethel et al (1976) made the only real attempt to relate weevil captures to potential infestation, but the resulting requirements for trap numbers and equation solving were such that grower acceptance was not forthcoming.

Although this method would not fit the classic IPM system in the minds of some, to this point it has proven the most effective approach considering the difficulties presented by the biology of the weevil. This approach has proven quite effective for weevil management but has collateral effects that in many instances demand a continued search for more optimal management methods. The dependence on foliar application of insecticide during the August - September time frame on a regular basis, especially with the most commonly recommended and used material (carbaryl), tends to disrupt the natural

complex of beneficial arthropods in the orchard, many times resulting in outbreaks of foliage feeding pests such as aphids and/or mites. When this occurs, it is many times imperative that additional spray applications be made in order to control those pests and preserve the tree foliage in good condition.

Pecan nut casebearer (PNCB). West of the Mississippi River, the pecan nut casebearer is considered the most significant arthropod threat to pecan production on an annual basis. In production areas of the Southeast, it has for many years been considered an occasional but potentially devastating pest, occurring in damaging populations only infrequently. A multivoltine, lepidopterous pest, PNCB undergoes three generations per year in most of the pecan production region. However, only the progeny of the first moth flight is normally considered a threat in the Southeast and only the first two in the West. The first seasonal generation of PNCB normally begins to be apparent by moth activity near the end of April in most of the production region. Unlike the weevil, the damaging larval stage can be readily controlled with timed application of insecticides. Therefore, infestation rates of the fruit clusters are used to trigger control decisions. Prior to 1996, past experience was largely relied upon to inform producers and scouts of when it was time to scout closely for signs of infestation in their orchards. In that year, however, a sex pheromone formula was released that has proven very effective for monitoring adult activity (Millar et al. 1997).

At the present time the pheromone lure is used with various traps and recommendations are to install traps in the orchard by the first week in April. When the first moth is captured, producers are instructed to begin to look for signs of fruit cluster infestation within 10 to 15 days. The traps continue to be monitored for evidence of adult population size, but controls are applied on the basis of actual infestation. Producers are advised in most areas to *treat if a through, random sample of at least 25 fruit clusters on each of 20 trees (500 fruit clusters per orchard) reveals an infestation rate (eggs, larvae or damage) of 2% if the crop load is light to moderate, or 5% if the crop load is moderate to heavy* (McVay et al. 1998). The treatment threshold is purposely keyed to crop load to; (a) encourage producers not to treat unless necessary, (b) allow beneficials to exert as much natural control as possible prior to spraying, and (c) take advantage of beneficial crop thinning

that can result from a light infestation in a heavy crop year. The pecan nut casebearer can truly be managed with IPM guidelines and often, especially in the Southeast production area, early season applications of chemistries disruptive to the orchard ecosystem can be avoided.

Hickory Shuckworm (HSW). Like the PNCB west of the Mississippi River, the HSW is considered the single most destructive insect pest on an annual basis in the Southeast. Like the weevil, the difficulty of post-ovipositional control of immature forms has dictated a monitoring program for adult populations. Organized IPM programs dating from 1976 have relied on specialized blacklight traps suspended in the tree canopy as the primary monitoring tool (McVay and Ellis, 1979, Smith and Tedders, 1978). Traps are suspended within the orchard in early June and operated, normally emptied daily, until the end of September. Early programs recommended treatment on the basis of specific numbers of adults captured, but grower acceptance of the traps with their associated maintenance problems was spotty, although a number did adopt the system and became very proficient at recognizing the small moths. As a result, some Extension program specialists have established blacklight monitoring site in orchards throughout their state's production region and provide producers with regular updates on HSW activity via toll-free telephone "hotlines" which the producer can access at any time. This provides the producer with flight activity information but unless their orchard is one equipped with a trap, they don't really know the activity level in their particular orchard and usually proceed on the basis of orchard history and crop load for that particular year. The information does provide for good timing of spray applications.

Smith (1985) developed and released a synthesized sex pheromone for HSW. Despite excellent results from its use as a monitoring tool in the western production region, this lure has failed to provide reliable information for producers in the Southeast. As a result, two methods of adult HSW monitoring are utilized in the respective regions with neither providing the perfect solution for a well defined IPM program.

The general recommendation for the most damaging generation of HSW is *when trap captures indicate adult activity is approaching a peak near the crop development stage of one-half shell hardening, make*

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two spray application fourteen days apart. This timing, many times, coincides with treatments for PW and some producers rely on PW sprays to suppress HSW populations below economic levels.

Yellow Aphid Complex (YA). Two species of aphids comprise a complex that, due to excessive application of broad-spectrum insecticides, was elevated in status from secondary pest problem to one of primary importance, at least from the producer's viewpoint. The larger of the two species, the blackmargined aphid (*M. caryella*) is considered the most damaging in large numbers, but both this species and the smaller yellow pecan aphid (*M. pecanis*) normally occur in mixed populations. Each species prefers specific feeding sites and several of each may be found on the same leaflet. There are usually two population peaks of YA during the growing season in most of the production belt. The first normally occurs during the second half of June and experiences an natural population crash within two weeks. This crash is brought about by a combination of factors; leaf conditioning, pressure from natural enemies and environmental. The second peak is not normally as predictable as the first and may occur any time in August or September and may not occur at all in some orchards. Those orchards that do experience large, late season peaks usually received applications of broad-spectrum insecticides for control of one or more of the major fruit feeding pests.

The first organized IPM programs established monitoring techniques and treatment levels for YA and periodically adjusted them as the years passed. Initial treatment thresholds were 30 to 35 aphids per leaf during the first summer peak and 10 to 15 per leaf during the later summer peak which occurs during the critical nut-filling phase of crop production (McVay and Ellis, 1979). As it became apparent that a complex that should normally be regarded as secondary from a pest standpoint was requiring more and more attention and chemical control, those treatment levels were increased several times. This was an attempt to reduce pesticide usage in what was becoming a losing battle with populations that were increasingly tolerant of the available insecticides. At the present time producers are encouraged to live with the aphid complex as much as possible. Current recommendations in the Southeast are to *ignore the early season peak and allow it to crash naturally and to treat the late season peak only if populations are such that*

feeding damage and related honeydew deposition is excessive. Growers are further encouraged to select insecticides for other pests that are the least damaging to the beneficial arthropod complex that exerts pressure on aphid populations.

Black Pecan Aphid (BPA). This aphid species is unlike the YA complex in that it normally occurs in much smaller populations but its feeding results in much greater damage to the foliage with the possibility of defoliation debilitating to the health of the tree. Prior to reliance on pesticides for general insect control, this species could have been considered a secondary or even an occasional pest in most orchards. The same events that led to serious problems with YA have elevated BPA to major pest status in some years. In recent years the BPA threat has appeared to increase and the species has shown some signs of tolerance to conventional pesticides that have normally provided excellent control and population rebounds soon after treatment have been observed.

Positive aspects of managing this aphid pest in an IPM system include the fact that it is relatively easy to scout for, it is known to prefer some specific varieties which can be used as indicator trees, and in the past has been easily controlled with low rates of pesticides that have little effect on YA populations. These characteristics are very important when it is considered that the damage potential of this aphid is such that the general recommendation for a treatment threshold began and remains *an average of one black aphid per compound leaf.* Some recent progress has been made in improving monitoring techniques and predicting imminent population outbreaks (Dutcher, 1997).

Pecan Leaf Scorch Mite (PLSM). The PLSM is another foliage feeder that can be considered an induced pest of commercial pecan orchards. Common in orchards throughout most of the production season, PLSM populations appear to be held in check by beneficial organisms unless released by events which disrupt that balance. The most common cause of that disruption is the application of broad-spectrum pesticides for control of other arthropod pests. Even then, orchards that are well irrigated or otherwise free of drought stress appear to withstand significant population levels with little damage. Other than occasional outbreaks accompanied by some defoliation following carbaryl applications for weevil control, PLSM did not seem

to present a significant threat in most years prior to the introduction of synthetic pyrethroid insecticides.

Population monitoring systems developed for PLSM were time consuming and did not meet with wide-spread grower acceptance. However, damaging mite populations tend to develop in localized "hot spots" within orchards. This trait is used in IPM efforts to avoid extensive damage by advising growers to observe the foliage in the shady areas of the lower canopy for indications of mite activity, including leaflet damage, active mites and the slight webbing produced on the underside of the leaflet. Treatment is recommended *when light to moderate damage with active mites present is found in 25% of leaf samples*. Producers are also encouraged to identify and treat the "hot spots" rather than entire orchards, depending on the extent of damage and other conditions.

Spittlebugs. As indicated in Table 1, two species of spittlebugs are commonly found in pecan orchards. There is some disagreement as to the damage potential of infestations, but in portions of the Southeast, it is not unusual to experience large outbreaks in the spring and early summer. Monitoring is accomplished by inspection of terminals during the scouting process and recording the percentage of terminals with spittle masses. General recommendations are to ignore all but those masses that are present in fruit bearing terminals. Treatment thresholds are to *treat when more than 5% of terminals with fruit clusters are found to be infested in May and June*.

Pesticides. Pecan IPM efforts have made good progress in the implementation of monitoring and treatment systems for the individual pest species. Application timing has improved and producers are aware of the need to choose the best control tactic at the best time for management of each individual pest. A major limitation has been the choice of materials available for pesticidal control applications. Almost without exception the materials available for commercial use have been broad- or relatively broad-spectrum in nature and the collateral effects on natural control of non-target species have continued to pose problems.

THE FUTURE OF PECAN IPM: NEEDS, REALITIES, AND POSSIBILITIES

As with any system or program involving biological entities, there is always new knowledge to be discovered and developed. Pecan IPM is certainly no exception. Although great strides have been made in monitoring systems and the understanding of the intricacies of the pecan orchard agro-ecosystem, there is room for continued improvement and recent developments in several areas bode well for the future. The following is an attempt to detail some of the needs of the pecan IPM system and to propose some possible solutions. All are interrelated to varying degrees so the discussions may tend to overlap but the author hopes that any redundancies will be excused. This is not an attempt to discredit or criticize any past efforts or contributions but is, rather, intended to hopefully stir the inventive minds of the professionals involved in pecan insect management toward even better results. Most of the needed contributions are certainly beyond the scope of the author's abilities.

Pecan Weevil. The two principal difficulties (precise monitoring and optimal control techniques) inherent in establishing a truly effective IPM program approach for any pest remain to be solved for this pest. Although existing methods of adult emergence monitoring are effective for timing control decisions, there is room for considerable improvement. The continued development of pheromones or other attractants that can be used in conjunction with existing trapping methods will hopefully result in improved pest detection and lead eventually to treatment thresholds that are sadly lacking at the present time.

Alternative control methodology is needed, not only to optimize management of the weevil but to lessen or prevent the collateral effects of the presently used foliar materials that are many times the effective choice available. Research is needed on both alternative application procedures (soil or trunk applied materials?) and on development of new chemistries that could prove target specific for the weevil with little or no effects on other species in the orchard ecosystem. There are now some such materials available for other pest species, hopefully the same will be true of the pecan weevil in the near future.

Pecan Nut Casebearer. Due to the recent developments in monitoring technology mentioned above, PNCB management is one of the real success stories of pecan IPM. The use of an effective sex pheromone attractant to detect and measure adult activity combined with relatively simple infestation rating procedures has greatly enhanced management of this pest. Add to this, the recent development and imminent registration of the lepidoptera-specific insecticide, tebufenozide, with others in the pipeline, and the PNCB situation has never looked better. Continued improvement will certainly be made but other pests demand more attention for the present.

Hickory Shuckworm. At present, two method of adult HSW monitoring are in place. Neither offers the optimal solution for a well defined IPM program. In the western, irrigated production area, the sex pheromone can be very useful, while in the Southeast, the blacklight trap has proven most efficient despite maintenance requirements. The need is for a site and species specific monitoring tool that will provide a true measure of activity during the HSW critical periods of the season.

It is known, from field research with the HSW sex pheromone, that for it to be effective at all, the trap and lure must be placed within the canopy of a tree that bears at least a moderate crop of pecans (author's unpublished data). This indicates that there is a karimone attractant associated with the presence of fruit that is much more powerful than the sex attractant. Adult moths appear to be attracted first to a tree with a crop load and, once within the canopy of the tree, to the less powerful sex attractant. Accordingly, a biochemical assay of volatiles associated with the immature pecan fruit could possibly yield an attractant that could be synthesized and used with pheromone-type traps to effectively monitor both populations and damage potential of the shuckworm.

If a more effective sampling technique can be developed, the use of newer, target-specific insecticides such as tebufenozide would bring HSW management to the same point of success as is now apparent for PNCB. The use of these chemistries to preclude collateral effects on beneficial organisms will prove of great benefit for late season HSW management.

Yellow Aphids, Black Pecan Aphid, Pecan Leaf Scorch Mite and Spittlebugs. The greatest improvement that could be made in the approach to IPM systems for these pests would be the improvements discussed above in the management of the three major fruit feeding pests. With some exceptions on a year to year basis, the primary problems associated with management of these foliage and twig feeding pests stems from efforts to manage the fruit feeders. The use of broad-spectrum insecticides for control of PW, PNCB, and HSW has been unavoidable for the most part and the materials have been very effective when properly timed and applied. Problems result from the disruption of the large complex of beneficial arthropods that can and will exert enough control on the foliar pest populations to maintain them below economically damaging levels if undisturbed.

This is an admittedly delicate balance and may not always have the desired effect. BPA populations, for example are considered damaging at very low levels and if it is the only foliar pest present, the numbers necessary to sustain beneficial populations could also cause significant damage. However, if YA and PLSM populations are also present at uneconomical levels the overall complex of beneficials would likely maintain BPA below damaging levels also.

Under present systems, applications of conventional pesticides disrupt the beneficial complex to the extent that populations of aphids and mites build to damaging levels extremely quickly and producers are many times forced to make additional insecticide applications to combat those pests. This is especially true following control applications directed at the pecan weevil and hickory shuckworm during the late summer. The problem is compounded by the fact that many aphid populations are tolerant of many of the available insecticides directed at them and mite outbreaks often follow the applications of some that are effective for aphids, thus the vicious cycle continues.

Recent improvement in aphid monitoring (Dutcher, 1997) are welcome and should pay dividends for the future of IPM in conjunction with reduced-risk, target-specific pesticides. The same improvements are needed for mite monitoring.

Pesticides. It is gladly noted that the same pesticide industry that brought us the conventional materials used for years in both pre-IPM and IPM arthropod management systems is making great strides in the development of reduced-risk, target-specific

pesticides, often referred to as Biorational materials. This is not to be construed as an indictment of the conventional materials. They were certainly state-of-the-art for their time and did the job very well in most cases. They were simply overused and misused due to our own shortsightedness and ignorance (ignorance is not necessarily bad, unless it goes uncorrected).

Already a couple of materials representative of the biorationals are labeled for use in commercial pecan orchards to some extent. These are tebufenozide, marketed as Confirm®, and imidacloprid, registered on pecans as Provado® and Admire®. Confirm is target specific for lepidopterous species such as HSW and PNCB in pecans, has proven very effective for their control with little if any effect on the beneficial complex in the orchard. Provado, or Admire, is fairly specific for piercing-sucking type insects such as aphids, phylloxeras, and spittlebugs. Like Confirm, it is safer to use, effective and has reduced effects on the beneficial complex as compared to conventional materials. Several additional biorational-type materials are currently being researched for efficacy against pest species of pecan and hopefully, several will make it to the market. If so, pecan IPM programs will be greatly enhanced.

If a reasonable arsenal of biorational materials is developed for use in pecan IPM, the programs will see many positive changes in the near future. This is especially true if target-specific materials that will provide pecan weevil control are included in the mix. Failing that, if alternative weevil control measures are developed that can be used in conjunction with biorationals for other pests, the need for artificial control of aphid and mite pests could conceivably decline greatly. The use of non-disruptive materials and/or methods for control of the three major fruit pests, could allow producers to rely upon natural controls for aphids and mites as well as the host of miscellaneous occasional pests. Indeed, for the first time in the Southeast, it would be feasible to use mass releases of beneficial arthropods to augment natural populations as an initial recommendation for aphid or mite suppression. The logical second step, if required, would be the use of imidacloprid or other target-specific biorationals for aphids or mites if necessary. Preliminary field research has indicated this to be a viable, cost-effective option to the application of conventional chemistries as now practiced (author's unpublished data).

Recent documented advances along with those discussed above could lead to streamlined pecan IPM systems that concentrate primarily on control of the major fruit feeding pests with foliar pests monitored but of true concern only under unusual circumstances. Only time will tell.

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Recorders Report for Entomology Session II
Marvin Harris, Professor of Entomology,
Texas A&M University

Paper by Ree on Casebearer:

Bill Goff Horticulturist, Alabama asked: Do
we know enough detail on the interaction of
first summer generation pecan nut
casebearer larvae and pecan to allow an
infestation to proceed until the crop is
thinned to the desired load and then stop the
infestation with a surgically timed pesticide?
This would be a possible tool to regulate the
crop load without having to shake trees in
August.

B. Ree and M. Harris replied: We know the
rate of nut consumption by casebearer larvae
(Ring, D. and M. Harris. 1984. Nut entry by
1st summer generation pecan nut casebearer.
Southw. Entomol. 9:13-21). Unfortunately,
the density of casebearer larvae is relatively
stable at about 20,000 larvae/hectare
regardless of crop load so that light crops of
250,000 nutlets/hectare suffer a 25%
infestation but didn't need thinning, and
heavy crops of 500,000 nutlets/hectare or
more have a 12% infestation or less and still
require thinning of an additional 30% or so
of the crop (see Harris, M., C. Chung and J.
Jackman. 1996. Masting and pecan
interaction with insectan predehiscent nut
feeders. J. Econ. Entomol. 25: 1068-1076).
Furthermore, insecticide efficacy cannot
presently be relied upon to exactly regulate
the precise degree of infestation.
Our current Texas recommendations usually
result in spraying light to intermediate crops
and not spraying very light crops, because
no harvestable crop can be produced, and
not spraying heavy crops because sampling
will show casebearer densities aren't high
enough to harm the crop. The use of *B.-t.*'s
is typically recommended with intermediate

crops that require some thinning but have
higher densities of casebearer than needed to
do that thinning. The short residual of *B.-
t*'s kills feeding larvae for a day or two but
allows adults, eggs and larvae already in
nuts to survive and develop to thin the crop
to some extent. Growers should be made
aware of the potential of casebearer as a
thinning agent with heavy to intermediate
crops as well as it's ability to devastate some
crops. Careful sampling for crop load and
the developing infestation will allow limited
use of this principle.
Brad Lewis Entomologist New Mexico State
also noted finding casebearer egg lays in
New Mexico in 1998 as high as 30% of
infested nut clusters that did not materialize
into larval populations that caused much
economic damage (only a few % infested
clusters at most). This continues the enigma
of pecan nut casebearer in the Mesilla and El
Paso Valleys since its discovery in the city
of El Paso in 1988. Dispersal has been
much slower than expected and economic
damage in unsprayed trees has, to date, only
been documented in one orchard near El
Paso. Current recommendations base the
need for spray application and timing on egg
density and larval hatch. This approach may
need to be reexamined in New Mexico and
Far West Texas where high egg/neonate
larval mortality appears to occur at least
under some circumstances. High
temperatures, low humidity, abundance of
natural enemies, etc., may be influencing
this situation differently in the Far West
compared to central Texas and requires
investigation.

Paper by McVay on Shuckworm:

No specific questions. Observations
indicate a need for better monitoring tools
for hickory shuckworm. Confirm® appears
to provide good control when needed

comparable to currently labeled materials.

Paper by Smith on hemipterans:

J. Benton Storey, Horticulturist, Texas A&M University asked: You noted differential infestation among varieties, can you explain this based on shell thickness and development at the time of infestation?

McVay answers: Shell thickness/hardness doesn't appear to govern (be correlated to) relative infestation. The polyphagous hemipterans appear to be sequentially monophagous, that is, they exploit many plant species during the season, but do so primarily one after the other as the development and attractiveness of each species waxes and wanes through time culminating in pecan at the end of the season becoming almost a default host when abundant densities of hemipterans have fewer and fewer alternatives. Pecan tree location and other factors besides shell thickness also appear to be important here. Trap crops may provide at least a partial answer to this problem.
L.J. Grauke, Horticulturist, USDA-ARS, Pecan Breeding Program asked: How do you measure shell thickness?

The consensus answer indicated relative subjective measures of shell thickness/hardness through time among varieties provided useful comparisons within a season at one location, but more objective measures were needed to make comparisons between locations and seasons to allow uniform analysis of this factor.

Paper by McVay on Pecan IPM:

Unidentified questioner asked: What role do hemipteran pheromones play in pecan IPM?

McVay answered aided by M.T. Smith:

Hemipteran pheromones are currently limited to *Euschistus* so that monitoring, trap out or other pheromone based stink bug (pentatomid) and leaf footed bug (coreid) management is unavailable for assessing the overall problem from the species complex. Trap catches of *Euschistus* are enhanced by pheromone usage, but trap out strategies must include other species where trap attractiveness is insufficient to reduce populations below economic levels.

General Comments by Recorder on Session

The participation by producers, horticulturists, plant pathologists, entomologists, agricultural economists, plant breeders and others representing research, extension, USDA, industry and production perspectives provided a range of inputs and responses that will stimulate further research, delivery and practice efforts that will benefit the pecan industry. The diversity of workshop participants and the interaction format designed into the program allowed information exchange among groups in a more fundamental way than is usual. Increasing these lines of communication in the limited time context of this workshop provides a catalyst and direction for further effort rather than a definitive final answer now. There is no forum for pecan as broadly represented as in this workshop and the emphasis on communicating both successes as well as problems across disciplinary and institutional lines encouraged broader thinking by all participants to improve the pecan industry. The quadrennial cycle now established by this third workshop allowed sufficient elapsed time for real progress in programs without losing relevancy. We look forward to greater interaction as a result of this workshop and achieving this standard again in 2002.

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APPENDIX 1

POSTER PAPERS

EFFECTS OF GLYPHOSATE EXPOSURE ON YOUNG PECAN TREES

Wheeler G. Foshee[1], William D. Goff[2], and Michael G. Patterson[3]

Additional index words. growth, yields, herbicides

ABSTRACT

Growth and yields were determined for 1st leaf and 4th leaf 'Sumner' pecan trees grown for three seasons under nine various treatments. Bark treatments did not effect the 4th leaf trees in regards to reduced growth or yields. Increased foliage exposure decreased both growth and yields. Bark exposure for the 1st leaf trees decreased growth in some instances. Growth declined with increases in foliage exposure, generally.

INTRODUCTION

Weed competition can reduce growth (Patterson et al., 1990), yield (Patterson and Goff, 1994), and nut quality (Daniell, 1974) in pecans. Several studies have shown that reducing all weed competition dramatically increase early growth and yields from young pecan trees (Foshee et al., 1997). The benefits from improved weed control are apparent. Glyphosate is a commonly used herbicide in many pecan orchards (Patterson, 1997). The purpose of this study was to determine the effects of various levels of glyphosate exposure to young pecan trees.

MATERIALS AND METHODS

Existing 4th leaf and newly planted 'Sumner' pecan trees were utilized in this study initiated in 1995 at the E.V. Smith Research Center located in central Alabama. The trees were planted on a 20 x 20-foot spacing. All trees were fertilized based on composite leaf and soil samples taken in July of each year

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(O'Barr et al., 1989). The experimental design was a randomized complete-block with nine treatments and six replications of each age tree (1st leaf and 4th leaf).

The orchard floor was maintained with recommended herbicides with the exclusion of glyphosate (Patterson, 1997). All data were analyzed with the GLM procedure (SAS Institute, Cary, N.C.) as a RCBD along with a least significant difference (LSD) mean separation and selected single-degree-of-freedom contrasts. Statistical significance was determined with a p value of 0.05.

Treatments were as follows: 1) mechanical weed free by disking (monthly), 2) standard glyphosate treatment - 2-3" on bark, 3) 1/3 bark level, 4) 2/3 bark level, 5) full bark level, 6) foliage 25%, 7) foliage 50%, 8) foliage 75%, and 9) foliage 100%. All treated trees received 1.0 lb. of active ingredient per acre applied to each side of tree three times during each growing season over a three year period. Data collected included: trunk cross-sectional area (TCSA), yields, grades, and photographs to document damage.

RESULTS

Older 4th Leaf Trees. All three-bark levels and the standard were significantly larger in TCSA than the foliage 50%, 75%, and 100% treatments (Table 1). As foliage contact increased TCSA dramatically decreased (Table 1). Contrasts showed that the collective bark treatments were larger in TCSA (78.0 than the foliage group (39.0) (Table 1). This same trend was observed for the yield data in 1997 (Table 2). The lowest yields came from the foliage 75% and 100% and these were significantly lower than all other treatments except the foliage 50% and full bark treatments. Contrasts showed the bark group with higher yield (1.42) as compared to the foliage group (0.58) (Table 2). Grade data was calculated and no differences were observed for percent kernel or total rejects (data not shown).

Young 1st Leaf Trees. The greatest effect on younger trees was from the foliage 100% treatment. It had the lowest mean TCSA as compared to all other treatments except the bark 2/3, foliage 50%, foliage 75% treatments (Table 3). Survival rates for the foliage treatments (25%, 50%, 75%, 100%) were 100%, 50%, 60%, and 0%, respectively. It appears that increased bark contact did affect the growth of

the trees, however the data is inconsistent. Trees receiving the bark 2/3 treatment were significantly smaller than the bark 1/3 or the standard glyphosate treatment (Table 3). A pre-selected F-test comparison showed that as a group the bark treatments (14.0) were larger in TCSA than the foliage treatments (9.0) (Table 3).

CONCLUSIONS

This study demonstrated that older, hardened off pecan trees (4th leaf and older) showed no adverse affect to bark exposure at any level over a 3-year period. Growth and yields were not adversely affected by these treatments. Even 25% foliage contact did not result in reduced yields or growth. However, increased foliage contact did reduce growth and yields.

The younger trees were adversely affected by exposure to the foliage. Increased bark exposure appears to have an adverse affect on growth of trees at this age. Foliage exposure did have statistical decreases in growth. No apparent damage was observed from minimal exposure to the bark on younger trees but that treatment is currently not a registered use.

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Table 1. Trunk cross-sectional area (TCSA) of young pecan trees (4th leaf) exposed to glyphosate following three-years of treatment (preliminary data) (November 1997).

Treatment	TCSA (cm^2)
Bark 1	76a^z
Bark 2	76a
Bark 3	81a
Standard	71a
Disking	64ab
Foliage 25%	73a
Foliage 50%	49b
Foliage 75%	20c
Foliage 100%	11c
SIGNIFICANCE *(P>F)*	
Treatment	.0001
F-TEST Comparisons *(P>F)*	
glyphosate (58)^y vs. none (64)	.2552
bark (78) vs. foliage (39)	.0001
bark-foliage (56) vs. none (64)	.1477
bark-foliage (56) vs. standard (71)	.0114

^{z}Mean separation within each column by LSD at P ≤ 0.05. Values followed by different letters are statistically different.
^{y}Contrast group mean.

Note: F-TEST comparisons
1. glyphosate vs. none: included all trees treated with glyphosate vs. the disking tree
2. bark vs. foliage: 1/3, 2/3, and 3/3 bark level vs. all 4 foliage levels.
3. bark-foliage vs. none: all of bark and foliage vs. disking treatment.
4. bark-foliage vs. standard: all of bark and foliage vs. standard (2-3" on bark).

Table 2. Yield of young pecan trees (4th leaf) exposed to glyphosate following three-years of treatment (preliminary data) (November, 1997).

Treatment	Yield (lbs./tree)
Bark 1	1.93a^z
Bark 2	1.43ab
Bark 3	0.97bcd
Standard	1.19abc
Disking	1.13abc
Foliage 25%	1.55ab
Foliage 50%	0.35cde
Foliage 75%	0.04de
Foliage 100%	0.00e
SIGNIFICANCE *(P>F)*	
Treatment	.0018
F-TEST Comparisons *(P>F)*	
glyphosate (0.98)^y vs. none (1.13)	.5206
bark (1.42) vs. foliage (0.58)	.0007
bark-foliage (0.95) vs. none (1.13)	.4508
bark-foliage (0.95 vs. standard (1.19)	.3447

^{z}Mean separation within each column by LSD at P ≤ 0.05. Values followed by different letters are statistically different.
^{y}Contrast group mean.

Note: F-TEST comparisons
1. glyphosate vs. none: included all trees treated with glyphosate vs. the disking tree
2. bark vs. foliage: 1/3, 2/3, and 3/3 bark level vs. all 4 foliage levels.
3. bark-foliage vs. none: all of bark and foliage vs. disking treatment.
bark-foliage vs. standard: all of bark and foliage vs. standard (2-3" on bark

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Table 3. Trunk cross-sectional area (TCSA) of young pecan trees (1st leaf) exposed to glyphosate following three-years of treatment (preliminary data) (November, 1997).

Treatment	TCSA (cm^2)
Bark 1	21a^z
Bark 2	9cde
Bark 3	12abcd
Standard	18ab
Disking	17abc
Foliage 25%	16abc
Foliage 50%	9bcde
Foliage 75%	7de
Foliage 100%	2e
SIGNIFICANCE $(P>F)$	
Treatment	.0037
F-TEST Comparisons $(P>F)$	
glyphosate (12)^y vs. none (17)	.1199
bark (14) vs. foliage (9)	.0273
bark-foliage (12) vs. none (17)	.0763
bark-foliage (12) vs. standard (18)	.0506

^{z}Mean separation within each column by LSD at P ≤ 0.05. Values followed by different letters are statistically different.
^{y}Contrast group mean.

Note: F-TEST comparisons
1. glyphosate vs. none: included all trees treated with glyphosate vs. the disking tree
2. bark vs. foliage: 1/3, 2/3, and 3/3 bark level vs. all 4 foliage levels.
3. bark-foliage vs. none: all of bark and foliage vs. disking treatment.
4. bark-foliage vs. standard: all of bark and foliage vs. standard (2-3" on bark).

REGULATING PECAN CROP LOAD BY SHAKING: LONG TERM RESULTS

William Reid[1]

Additional index words. Mechanical fruit thinning, alternate bearing,. *Carya illinoinensis*

ABSTRACT

Mechanical fruit thinning has proven to be a valuable cultural technique for mitigating the negative effects of fruit over production in pecan. What is not known is how mechanical fruit thinning affects the long term cropping patterns of a pecan orchard. In a study conducted in Kansas, 'Giles' pecan trees were subjected to two fruit thinning treatments—thinning the fruit of trees with greater than 65% fruiting shoots and no fruit thinning. In this five year study (1993-1997), trees that were maintained at the 65% fruiting shoot level had a significantly lower index of alternate bearing than untreated trees. During the first three years of the study, the number of trees that required shaking decreased each year indicating that yield per tree can be stabilized over time. In contrast, trees not receiving the thinning treatment displayed a typical alternate year bearing pattern. However, a severe drought in the fourth year of this study, seriously limited the crop in this unirrigated orchard. Without a significant crop load during 1996, all trees produced a over supply of flowers in 1997, regardless of previous fruit thinning treatment. The results of this study confirms that an irregular bearing pattern of a pecan orchard is initiated by major weather events such as drought, spring frost, flooding, and winter cold. However, annual mechanical fruit thinning can promote regular pecan production between major climate events.

INTRODUCTION

Mid-summer tree shaking is an effective technique for regulating pecan (*Carya illinoinensis)* crop load (Reid *et al*. 1993, Smith *et al.* 1993, Goff *et al.* 1995, Sparks et al. 1995). By removing a portion of an excessive fruit crop, growers can improve nut quality, reduce shuck decline, reduce vivipary, and increase return bloom (Reid *et al*. 1993, Smith *et al.* 1993, Goff *et al.*1995, Sparks *et al.* 1995). However, the long-term effects of an annual program of mechanical fruit thinning on pecan bearing patterns is unknown.

METHODS AND MATERIALS

Twenty 'Giles' trees were selected for this study from an orchard growing on the Pecan Experiment Field near Chetopa, KS. These trees were established in 1965 and averaged 40 cm DBH. Mid-summer tree shaking was used on one half of these trees to regulate the crop load to no more than 65% fruiting shoots. Limiting fruiting to >65% fruiting shoots was based on previously reported research for the 'Giles' at this Kansas location (Smith *et al*. 1993). Trees received the shaking treatment when fruits achieved the ½ water stage. The remaining trees were left to fruit naturally. When the study was initiated in 1993, trees were blocked by fruit load allowing for a randomized block experimental design. The percent of shoots fruiting on a tree was estimated by sampling a 2 m^2 area in the mid-portion of the tree's canopy. In 1993, the nut crop load on 'Giles' ranged from 30% to 89% fruiting shoots. In each subsequent year, percent fruiting shoots was estimated (as mentioned above) and shaking treatments applied to treatment trees when the fruit load exceeded 65% fruiting shoots. The study was continued for 5 years. The numbers of trees requiring shaking to lower fruiting to <65% fruiting shoots was recorded annually. Yield data was collected annually and were statistically analyzed using SAS-ANOVA (SAS 1988). Yield of each tree was determined by weighing the nuts that were harvested and cleaned with commercial pecan harvest equipment.

To help understand the effect of fruit thinning on alternate bearing an evaluation of intensity of deviation in yield in successive years was calculated using the method of Gur *et al.* (1969). Differences in alternate bearing intensity (denoted as I) between treatments were evaluated using SAS-ANOVA (SAS 1988).

To confirm previous research results, nut quality data was recorded for the very heavy 1997 crop. Nut weight, kernel weight, and percent kernel were determined for a 20 nut sample take from each tree. Data were analyzed with SAS-ANOVA (SAS 1988).

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RESULTS AND DISCUSSION

Eight of ten trees required shaking during the first year of this study to provide the <65% fruiting shoot treatment. In subsequent years, the number of trees requiring shaking to maintain <65% fruiting shoots decreased annually until 1996 (Table 1). During the late summer of 1995, Kansas experienced a major drought that lasted until the spring of 1996. Drought stress seriously limited the number of pistillate flowers produced by all trees in this unirrigated orchard. Without a significant crop in 1996, all trees cycled "on" in 1997 with over 93% of terminals bearing pistillate flowers. All trees in the <65% fruiting shoot treatment required shaking in 1997.

Table 1. The number of 'Giles' trees requiring tree shaking to achieve the <65% fruiting shoot treatment during the years 1993-1997.

Year	Percent of Trees Requiring Shaking
1993	80
1994	50
1995	30
1996	0
1997	100

Nut yield (expressed as kg of clean nuts) was unaffected by fruit thinning treatment (Pr>F >.20) (Table 2). However, simple yield data does not tell the whole story in an orchard populated with trees with variable bearing patterns. Within any one year, yield per tree varied widely in the control group, while the yield of trees receiving fruit thinning was more consistent. During the first three years of the study (1993-1995), the intensity of deviation in yield (I) was significantly (Pr> F = .0026) smaller for trees receiving fruit thinning than for control trees (Table 3.). The drought induced crop failure in 1996 increased I for the years 1995-1997 for all trees regardless of fruit thinning treatment.

Similar to previous reports (Smith *et al.* 1993, Goff *et al.* 1995, Sparks *et al.* 1995), nut weight, kernel weight, and percent kernel was significantly greater for trees receiving the shaking treatment in 1997 (Table 4). During this year, nuts produced by trees in the control group had such poor quality that they were unmarketable.

Table 2. Mean yield (kg), maximum yield, and minimum yield for 10 'Giles' trees receiving annual crop load regulation and 10 'Giles' trees that did not during the years 1993-1997

Year	Treat-ment	Mean Yield (kg)	Max. Yield (kg)	Min. Yield (kg)
1993	Control	21.9	39.0	10.4
	Thinned	19.8	24.0	12.0
1994	Control	20.9	48.1	5.4
	Thinned	22.4	29.7	18.1
1995	Control	14.6	28.6	4.5
	Thinned	18.7	25.6	13.8
1996	Control	2.4	3.2	1.8
	Thinned	2.5	3.2	1.4
1997	Control	22.9	34.0	7.9
	Thinned	23.2	28.4	20.0

The results of this study confirms that an irregular bearing pattern of a pecan orchard is often initiated by major weather events such as drought, spring frost, flooding, and winter cold (Monselise and Goldschmidt 1982). However, annual mechanical fruit thinning can reduce the tendency for alternate bearing of pecan between yield limiting climatic events.

Table 3. The intensity of deviation in yield (I) for 'Giles' trees that received a fruit thinning treatment and 'Giles' trees were allowed to bear naturally (control). Deviation in yield was significantly (Pr> F = .0026) smaller for trees receiving fruit thinning than for control trees over the years 1993-1995. A serious drought set all trees into an alternate bearing pattern starting with the crop failure of 1996.

Years	Intensity of Yield Deviation (I)	
	Control	Fruit Thinned
1993-1994	43.7	7.5
1994-1995	53.0	9.4
1995-1996	62.8	70.6
1996-1997	76.9	80.3
1993-1997	59.1	43.2

Table 4. The influence of fruit thinning on nut weight, kernel weight, and percent kernel produced by 'Giles' trees in 1997.

Treatment	Nut Weight.(g)	Kernel Weight (g)	Percent Kernel
Control	3.96	1.79	44.8
Thinned	4.48	2.29	50.8
Pr > F	.0001	.0001	.0001

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INFLUENCE OF PECAN CULTIVAR AND SOURCE OF INOCULUM ON DEVELOPMENT OF PECAN SCAB

C.R. Bracewell and K.L. Stevenson[1]

Additional index words. Host resistance, pathogenesis, disease development

Pecan scab, caused by *Cladosporium caryigenum* (Ell. et Lang.) Gottwald, is the most important disease of pecan (*Carya illinoensis* (Wang.)K.Koch) (Gottwald 1982). Immature shoots, twigs, leaves, and nut shucks are highly susceptible to infection by *C. caryigenum* (Gottwald 1985). Scab lesions are typically brown to black, olivaceous and velvety in appearance and severe infections can result in shoot and twig dieback .

Cladosporium caryigenum overwinters as subcuticular stromata in lesions on twigs, petioles, and nut shucks. Conidia produced in stromata in the spring are the primary inocula, and conidia produced in lesions throughout the growing season are the secondary inocula. Conidia are disseminated by wind and rain to susceptible young tissues. Conidia germinate and *C. caryigenum* infects host tissues subcuticularly when free moisture is present (Gottwald 1985, Latham and Rushing 1988). Though partial cultivar resistance to scab is available, control of this disease is primarily attained through the use of protectant and systemic fungicides (Ellis et al. 1998).

The long-term value of cultivar resistance to scab is limited by the ability of *C. caryigenum* to adapt to overcome that resistance. There is clear evidence for such pathogenic specialization in *C. caryigenum*. Different strains of the fungus appear to exist at different locations. A given cultivar may appear to be quite resistant at one location but may be found to be susceptible at another. Cultivars that were resistant to scab infection in the early days of the pecan industry, such as San Saba, Georgia, and Delmas, are now found to be scab susceptible (Cole 1957, Demaree and Cole 1929). The existence of different pathogenic strains on different cultivars and at different locations presents important considerations for the screening of pecan cultivars for scab resistance, as different strains may be present at different locations. Researchers testing the

resistance of a given cultivar to scab should take care to include many sources for the *C. caryigenum* used in disease trials.

A clearer understanding of the pathogenic specialization of *C. caryigenum* would provide important information about the biology of this fungus and host resistance in pecan cultivars. Further information about pathogenic variation that occurs in *C. caryigenum* would be valuable in developing improved screening programs for cultivar resistance and the development of new scab-resistant pecan cultivars. Pathogenic variation in *C. caryigenum* was examined in this study by testing the effect of source of inoculum on infection of resistant and susceptible pecan cultivars. The study consisted of two experiments. The first experiment was a whole-plant inoculation study in which the interactive effects of source of inoculum and cultivar on symptom development were investigated. The second experiment was a detached leaf study in which the interactive effects of cultivar and source of inoculum on conidial germination, appressorium formation, and subcuticular fungal growth were compared.

In the first experiment, container-grown partially resistant (Sumner) and susceptible (Wichita) pecan cultivars were inoculated with conidia of *C. caryigenum* obtained from each cultivar. Leaf wetness was maintained on inoculated trees for 48 h at 25 C in growth chambers. Disease intensity was evaluated 17 days post inoculation, by visual estimation of disease severity (percent diseased tissue) and by counting the number of lesions per leaflet. The experiment was repeated for a total of three experimental trials. There was a significant effect of the cultivar-inoculum source on resulting disease intensity. The isolate of *C. caryigenum* from Wichita caused significantly less disease on Sumner trees than on Wichita trees. The isolate from Sumner caused significantly more disease on Sumner trees than did the isolate form Wichita. Apparently the isolate from Sumner had adapted to overcome the resistance of Sumner.

The presence of chlorotic halos in the resistant Sumner infections and the cross-inoculations of Wichita trees with inoculum from Sumner indicates that though these lesions were apparently smaller and less velvety in appearance, some disease reaction occurred. This kind of chlorotic halo is typical of the hypersensitive response that has been documented in other plant-pathogen interactions. It also indicates that physiological effects resulting from infection of *C. caryigenum* extend beyond the dark, central portion of the lesion where sporulation is evident. Converse

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(1960) reported similar chlorotic reactions in self and cross inoculations with four susceptible cultivars. Turechek (1995) found that lesions on leaves of the resistant cultivar Eliott and the moderately susceptible cultivar Cape Fear were similarly smaller and less velvety in appearance than lesions on the susceptible cultivar Wichita.

In the second experiment, detached leaves from Sumner and from Wichita were inoculated with conidia of *C. caryigenum* isolates obtained from each cultivar. Leaf wetness was maintained at 24 C for 96 h and leaf disks were sampled at 24, 48, 72, and 96 h after inoculation. Percentages of potential infection sites with germinated conidia, appressoria, and subcuticular growth were recorded. The cultivar-inoculum source interaction had no effect on an of these early infection events, up to and including subcuticular growth. The timing of these events was similar to the progression of these events in an earlier study of development of *C. caryigenum* on leaves of the susceptible pecan cultivar Schley (Latham and Rushing 1988). The percentage of each of these early stages of fungal development was not significantly different between 72 h and 96 h post inoculation.

This study has delimited a time period when the mechanisms of resistance and pathogenic variation are likely to be expressed. In the whole-plant experiment, there was a significant effect of the cultivar-inoculum source interaction on disease development. Significant differences were observed in disease intensity resulting from inoculations of Sumner pecans (resistant) and Wichita pecans (susceptible) with *C. caryigenum* isolated from each cultivar. At 72 h (3 days) post inoculation in the detached leaf experiment, there were no significant differences in the frequency of subcuticular growth between the cultivar-inoculum source combinations. Germination, appressorium formation, and subcuticular growth were not significantly different between 72 h (3 days) and 96 h (4 days) after inoculation. These results indicate that the observed differences in disease intensity in different cultivar-inoculum source combinations that appear in symptom development result from differences in fungal development between 96 h (4 days) and 17 days post inoculation. Since visible symptoms were first observed at 10 days post inoculation in each experimental trial, differences in infection resulting from specific cultivar-inoculum source combinations should be observed between 4 and 10 days post inoculation. These differences in fungal development may be manifested as differences in rate and extent of subcuticular growth.

This study provides clear evidence for pathogenic variation in *C. caryigenum* and delimits the time period where the resistant response of pecan cultivars to infection by *C. caryigenum* is likely to occur. This information about cultivar-specific pathogenic variation in *C. caryigenum* contributes to our basic understanding of varietal specialization in the imperfect fungi, an area in which there has been relatively little research. More research of pathogenic variation in *C. caryigenum* would also provide important information for pecan growers, since the long-term value of scab-resistant pecan cultivars is limited by the ability of the pathogen to overcome that resistance. Resistance screening for cultivar resistance to scab can be improved by using inoculum from multiple isolates of *C. caryigenum* in resistance trials. The observed differences in disease resulting from the specific cultivar-inoculum source combinations and the critical time period that has been delimited offer a unique opportunity to study pathogenic variation and resistance mechanisms in this economically devastating pathogen of pecan.

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SUNLIGHT DISTRIBUTION BEFORE AND AFTER PECAN ORCHARD THINNING : ITS INFLUENCE ON YIELD AND SHOOT GROWTH

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Additional index words. Sunlight distribution, solar hour, tree canopy, tree spacing, shoot growth, nut production and quality.

ABSTRACT

This experiment was carried out during 1995, 1996 and 1997 in an orchard thinned at different stages from 25 to 50% in 1993, 1994 or 1995. Sunlight distribution within the tree canopy before and after thinning and its effect on shoot growth, nut production and nut quality were investigated. Sunlight distribution within tree canopy measured from late June to late July in 1996 and 1997 was higher in an orchard area where trees were thinned 25% in 1994 and 25% in 1995. Shoot growth during 1995 and 1996 was higher for trees thinned 25% in 1993 and 1994. For trees thinned finally to 50% in 1995 higher shoot growth occurred during all three years of the study. A trend for increasing nut yield was shown in thinned trees. The effect on nut quality was not related to thinning but to crop load.

In pecan orchards with high densities (at least 100 trees per ha), maximum sunlight interception is observed when trees reach maturity; however, its distribution within the tree canopy is notably reduced. As a result of decreased sunlight penetration, shoot growth and photosynthesis rates are negatively affected. In addition, a low kernel percentage followed by alternate bearing as well as limited growth and low production is observed (Herrera, 1994; Mc Eachern, 1996)

Shading has become a major problem for New Mexico pecan orchards because the vast majority of the trees are over 20 years old (Herrera et. al, 1992). In crowded orchards when light distribution becomes a major limiting factor, various alternatives can be taken to correct it. One of these is tree canopy

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management to improve sunlight distribution optimizing the relationship between vegetative growth and fruiting during the current season as well as over the life of the tree. The first objective in canopy management is to reestablish trees that have a manageable height (Wood, 1997).Reduction in tree size can be accomplished either by severe heading cuts or by removing selective limbs. Orchard thinning is another alternative to increase sunlight distribution in pecan orchards, "sunlight management" must be kept in mind before tree removing begins (Herrera, 1996).

Mature pecan tree canopies in non crowded orchards generally intercept a maximum of 65 to 70% of the available sunlight (Wood, 1997). Once the tree canopy develops, spacing is the most common cause of stress. Then the orchard trees shade each other, and suffer from lack of sufficient vigor because bottom branches are overgrown by the tree tops and light penetration is reduced. Sunlight distribution is an important aspect of orchard management, specially in regards to its effects on growth, nut production and quality. Pecan leaves require high light intensity to operate at maximum physiological efficiency. Light intensity decreases within the tree canopy as the outer portion shades the inner canopy (Wood, 1991). For example, outer full sunlight leaves of 'Cape fear' pecan trees, showed maximum photosynthetic efficiency at 1500 $\mu mol\ m^{-2}\ sec^{-1}$ (from 2,000 $\mu mol\ m^{-2} sec^{-1}$ considered as maximum photon flux density at noon on a clear summer day) while shaded leaves required 1300 $\mu mol\ m^{-2}\ sec^{1-}$ with lower photosynthetic efficiency (Andersen, 1994). Results of that study showed that leaves located in the outer canopy were light saturated about 3/4 full sunlight. However, shaded leaves were saturated at about 2/3 full sunlight meaning that shaded leaves are not operating at maximum efficiency. Based on the importance that sunlight distribution in mature orchards has, the following hypothesis was developed and tested: sunlight distribution in mature crowded trees is reduced, consequently shoot vigor, nut production and quality are reduced.

MATERIAL AND METHODS

The experiment was initiated in 1995 in an orchard located south of Las Cruces, New Mexico. Trees in the orchard were originally planted on a 30 X 33 ft spacing. In four different sections of the orchard (one in 1993, two in 1994 and one in 1995), 25% of the trees were removed diagonally along alternate tree rows where trees were spaced 33 ft apart. After thinning, the orchard had a diagonal row with trees

spaced 33 ft apart while the adjacent rows had every other tree removed with trees spaced 66 ft apart. It actually makes a trapezoid shape where trees along the base line are spaced 60 ft and trees on the top line are spaced 30 ft with side lines measuring 33 ft between trees. In 1995 50% of the trees were eliminated in one 1994 section. Trees in this section were spaced 60 X 33 ft on a diagonal shape. For this study the experimental trees were selected from: a) non thinned orchard section; b) orchard section thinned 25 percent in 1993, 1994 or 1995; c) orchard section thinned first to 25 % in 1994 and to 50% in 1995. In some orchard sections, sunlight distribution within and between trees was measured before and after orchard thinning, sunlight measurements were taken on a 4 tree sample representing each thinning practice. Tree canopy was divided into six horizontal 1.5 segments at 1.5, 3, 4.5, 6, 7.5 and 10 m from the ground. These sections were located perpendicular to the trunk (parallel to the orchard ground). Also eight vertical sections parallel to a vertical trunk, four on each side of the tree at 1.5, 3, 4.5 and 6 m from the trunk were considered. To get to each canopy position a pruning tower was used. An anchored string line with marked segments of 1.5 meters was used along with marks made on the ground at 1.5, 3, 4.5 and 6 meters on each side of the trunk. Readings were taken at points where horizontal and vertical lines crossed each other. Readings in each point were reported as percent sunlight considering the ratio between readings taken both outside in full sunlight and inside the tree canopy. Readings were taken from late June to late July at 9, 12, and 15 solar hours with a LI-COR Line Quantum sensor (LI-191 SB) on eight sides of the tree as follows: north, south, east, west, northeast, southeast, northwest and southwest directions. To evaluate shoot growth, ten shoots located in the outer periphery from each of the eight canopy planes on each tree were randomly selected in 1995 and tagged, for determining apical shoot growth in 1995, 1996 and 1997. Yields were estimated from all selected trees individually in 1995, 1996 and 1997 using the methodology suggested by Worley and Smith (1984). Pecan quality represented by kernel percent was calculated from a 40- pecan sample taken from each tree. All data were analyzed using a completely random design and means were separated using Tukey's test (α =0 .05).

RESULTS AND DISCUSSION

Sunlight distribution in 1996 and 1997 inside the tree canopy was significatively higher in those trees where final orchard thinning (50%) was carried out

in 1995 leaving 73 trees per ha (Fig. 1). In both years, the lowest light level within the tree canopy was observed in the unthinned area trees (122 trees per ha). Low sunlight distribution within the tree canopy for the highest tree density area was probably due to shading induced by tree crowding. Sunlight distribution was not different than the control in trees corresponding to 25% thinned area performed during 1994 and 1995. High sunlight distribution was found in trees corresponding to 1993 thinning, apparently because some big branches were lost due to shading which changed the tree canopy architecture.

For readings at 9, 12 and 15 hrs in 1996, the calculated average sunlight distribution percent within the tree canopy was higher for the 1993 thinning and for the lowest tree density where the thinning was done in 1995 (Fig. 2). Similar results were observed in 1997 (data not shown). The highest sunlight distribution within the tree canopy occurred in the lowest tree density after thinning because of the uncrowded tree canopy. In relation to sunlight distribution on different tree sides, in crowded trees (122 trees per ha) measurements of sunlight distribution (from 13% for NW side to 27%for W side) within the tree canopy in 1996 were similar whether made in north, south, east and west, northeast, southeast, northwest or southwest sections. However, as orchard density decreased after thinning, sunlight penetration varied notably (from 8% for NW to 57% for SW) in the different tree canopy sides (Fig.3). Similar results were found in 1997 (data not shown). This light distribution pattern was caused by the tree density, orchard configuration and especially tree canopy architecture. Considering all eight tree sides, a low average sunlight distribution of only 18% for crowded trees indicate that shaded leaves located in both the periphery and interior canopy were not light saturated. A similar situation was observed in uncrowded trees especially inside the canopy where average sunlight penetration was 30 % . Since individual leaves operate at maximum photosinthetic efficiency at 3/4 of full sunlight (Andersen, 1994), only top and outside peripherical canopy leaves were sun -exposed at any solar time for uncrowded trees. In crowded trees, only the foliage located in the canopy top could be light saturated, consequently, a large portion of the tree canopy was not saturated. Low photosynthesis rate is due to reduced sunlight distribution, resulting in a negative effect on pecan productivity (Andersen, 1994).

In 1995, 1996 and 1997, shoot growth in the outer periphery of the canopy was significantly lower in the unthinned trees. Shoot growth during 1995 and 1996 was significantly higher for area trees thinned 25% in 1993 and 1994 as well as for the trees thinned 50% in 1995; but in the latter, it occurred during all three years the data was taken (Fig. 4). The decrement in shoot growth for high tree density areas among the years was induced by tree crowding. These results are in good agreement with other research (Herrera, 1994; Mc Eachern, 1996; and Wood, 1997). In mature crowded orchards sunlight distribution is hindered, negatively affecting shoot growth. Nut production on a per tree basis was not affected significantly by thinning. However, in 1995 and 1997, which were high crop level years, there was a trend for nut yield to increase in thinned trees (Fig. 5), especially for those trees where 25% thinning was carried out in 1993 and 50% thinning was completed in 1995. Crowded orchards suffer from lack of sufficient vigor (Wood, 1997). Consequently, nut production and quality are limited (Herrera, 1994; Mc Eachern, 1996). Kernel percent was not altered significantly by tree thinning year (Fig. 6). The major effects were related to crop level of the individual year.

CONCLUSIONS

The main conclusions derived from this study relates to average daily percent light distribution which increased as tree density was reduced after thinning. Shoot growth from the periphery of the outer canopy increased as tree density decreased. Nut yield tended to be higher in 1995 and 1997 for thinned trees. Nut quality was related to tree crop load of the individual year. These findings support the stated hypothesis that sunlight distribution in pecan trees is reduced when orchards become overcrowded, resulting in reduced shoot growth, nut production, and quality.

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Sunlight (%)

50
40
30
20
10
0

1996
1997

c

AB

AB

BC

BC

C

A

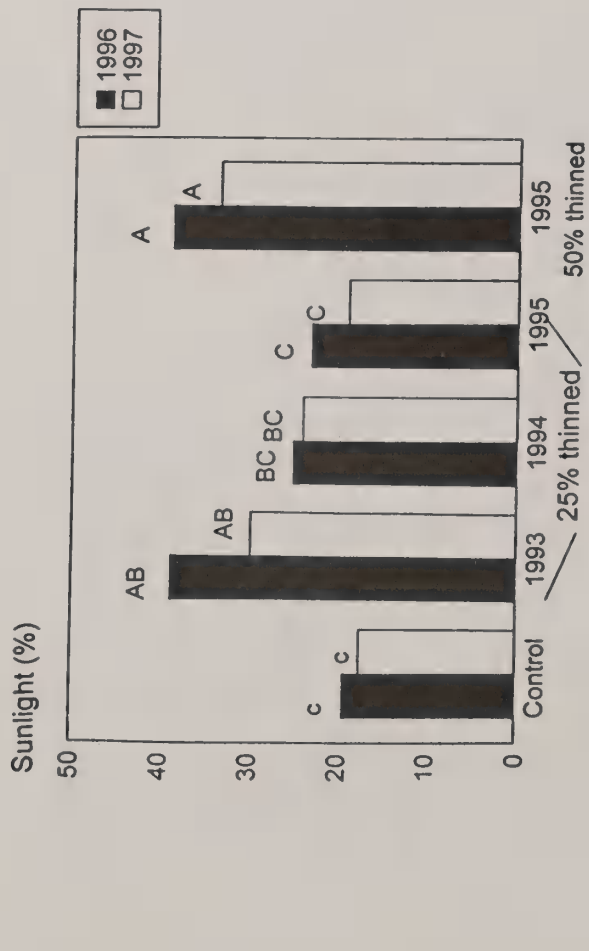Control

1993   1994   1995
25% thinned

1995
50% thinned

Figure1. Sunlight distribution within the tree canopy 1996 and 1997 for different thinning years. Bars topped by the same letter within the same year are not significantly different at the 5% level.
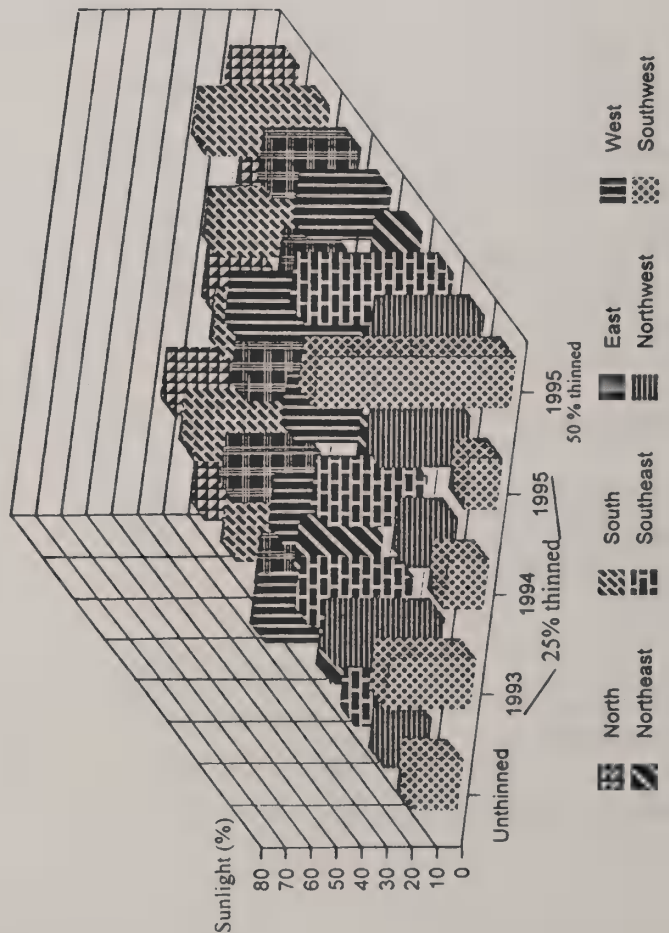
192

Sunlight (%)

50
40
30
20
10
0

9:00   12:00   15:00
Solar hour

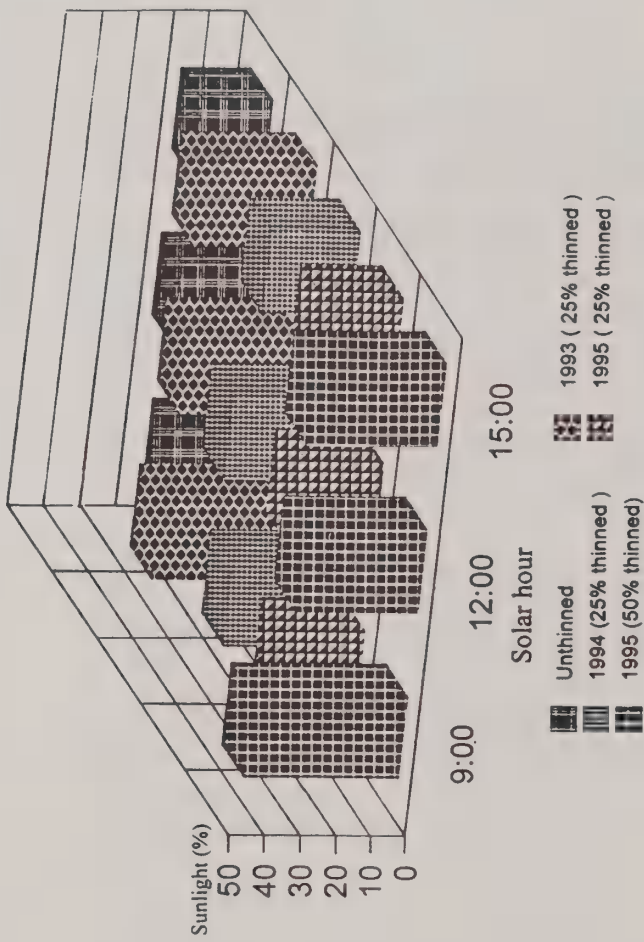Unthinned
1994 (25% thinned)
1995 (50% thinned)

1993 (25% thinned)
1995 (25% thinned)

Figure 2. Sunlight distribution within the tree canopy in 1996 in different solar time for three thinning years.

Sunlight (%)

80
70
60
50
40
30
20
10
0

Unthinned

1993   1994   1995
25% thinned

1995
50 % thinned

North
Northeast

South
Southeast

East
Northwest

West
Southwest

Figure 3. Sunlight distribution patterns within the tree canopy in 1996 for three thinning years.

Shoot length (cm)

12

10

8

6

4

2

0

1995
1996
1997

B

B

C

A

A

B

A

A

B

B

B

BC

A

A

A

Control

1993   1994   1995
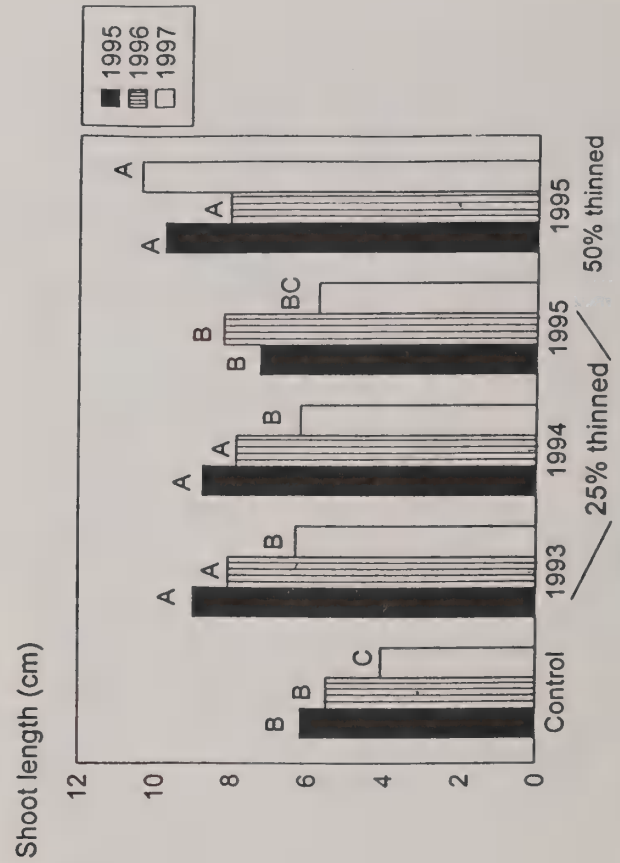25% thinned

1995
50% thinned

Figure 4. Shoot growth for different thinning year. Bars topped by the same letter within the same year are not signi ficantly different at the 5% level.
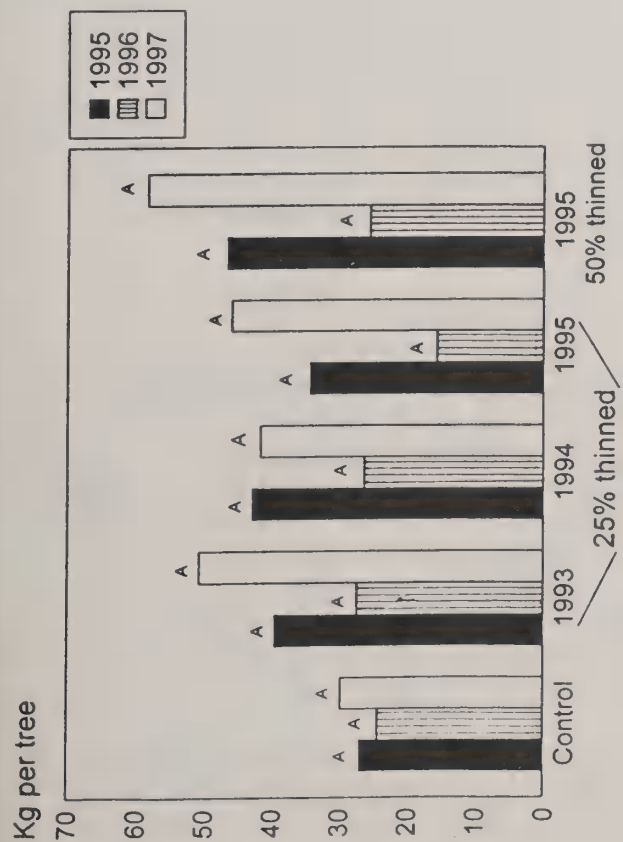
Kg per tree

Figure 5. Pecan production for different thinning years. There were no significant differences among years at the 5% level.
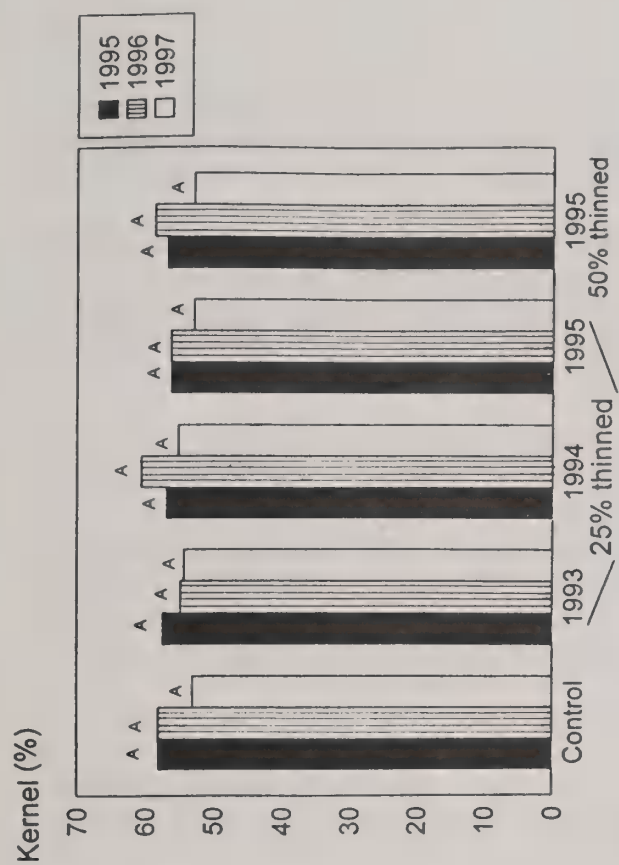
Kernel (%)

Figure 6. Nut quality for different thinning years. There were no significant differences amomg years at the 5% level.

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PRODUCTIVE PERFORMANCE OF 14 PECAN CULTIVARS IN THE ARID ZONE OF THE NORTH OF MEXICO.

A. Lagarda M., M.C. Medina, M., and J. Arreola A.[1]

Additional index words: Alternate Bearing, Cultivars, Yield Efficiency, Trunk Cross Sectional Area.

ABSTRACT

The irrigated pecan producing area in North Central Mexico is based on the cultivar 'Western Schley'., approximately 70% of the cultivars planted in the region.

To search for new cultivars with good yield and quality of nuts as a complement or alternative to 'Western Schley', we evaluated fourteen cultivars during a nine year period (1986-1995), by recording, at tree level, inshell nut production, percentage of kernel, and trunk cross sectional area (TCSA). These data were used to calculate indexes for yield efficiency (YE), alternate bearing and long term productive performance, which were used as main criteria for cultivar evaluation.

In a nine year consecutive harvest evaluation, yield efficiency of the cultivars varied from 18 to 51 g inshell nuts/cm2 TCSA all similar statistically. 'Western' (40), 'Wichita' (40), 'Cherokee' (40) and 'Shoshoni' (51 g/cm2 TCSA), reported the higher yield efficiency values.

Percent of kernel varied from 47.1% in 'Frutoso', to 62.5% in 'Wichita'. Only four cultivars yielded less than 55% of kernel: 'Cape Fear' (54.3%), 'Tejas' (54.7%), 'Shoshoni' (52.8%) and 'Frutoso' (47.1%).

Alternate bearing index (ABI) fluctuated from 38% up to 105% among cultivars. Considering this range, 50% ABI was choosed as a maximum value for selecting cultivars with acceptable alternating behavior. 'Cape Fear' (38%), 'Tejas' (48.9%) and 'Western' (43.9%) are the cultivars with more stability in nut production.

The Long Term Productive Index (LTPI), was considered to select cultivars with values closest to 1. Only 'Western' (0.91) had the highest value and 'Cape Fear' (0.52) and 'Wichita' (0.53) were the closest.

From this study we conclude that: 'Western' is the best qualified cultivar producing high yield, maximum LTPI and acceptable quality. No other cultivar behaved as good as 'Western'; cultivars like 'Wichita' and 'Cape Fear', with good quality and fair LTPI, may be used as polinators for 'Western'.

INTRODUCTION

The pecan industry in Mexico is located mainly in the North Central part with a reported 50,000 Has., producing 35,000 tons in shell pecan nuts per year (Anonimo, 1980).

Since 1950, the pecan industry began to grow based in a number of pecan cultivars selected out of the commercial groves (Lagarda, 78).

Many pecan cultivars have been introduced to the producing areas of Mexico, among them are: 'Western Schley', 'Barton', 'Burkett', 'San Saba improved', 'Wichita', 'Squirrel Delight', 'Stuart', 'Success', 'Choctaw', 'Mohawk', 'Shoshoni', 'Cherokee', 'Tejas', 'Cheyenne', 'Shawnee' and others (Lagarda, 1978).

Pecan production in Northern Mexico has been developed on the basis of paper shell cultivars which yield a percent kernell higher than 55% (Medina et al., 1996). These cultivars were seclected, for nut yield, alternate bearing, and fruit quality characteristics such as percentage of kernell, kernell color, and nut size (Lagarda et al., 1997). Cultivars such as 'Western Schley' and 'Wichita' fulfill these requirements which accounts for 70% of the pecan production in Mexico (Medina et al., 1996).

Pecan production in this region is undertaken considering full irrigation, intensive management and minimum usage of

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parasiticides, which allow a production with an 80% premium nut quality and no contamination.

Alternate bearing of the pecan cultivars has been reported all over the producing areas; however, differences in the yield stability is reported for certain groups of cultivars (Lagarda, 1990, Sparks and Madden, 1985).

It has been well accepted that a 50% variation of the nut yield among the on and off year production for mature pecan trees is the result of a good management and a good cultivar combination (Johnson and Weinbaum, 1987). Nevertheless, there are cultivars such as 'Western Schley', that can maintain these values, whereas many others such as 'Barton', 'San Saba improved', 'Burkett', etc., have an alternate bearing value higher than 60% (Lagarda, 1978; Sparks, 1979).

On the short term, production of inshell pecan nuts on a per area basis has been reported to reach the 4000-5000 kg/ha; however, in a long term basis, where alternate bearing is considered, the optimumn yield is reported as 1800-2000 kg/ha (Lagarda, 1995).

Many efforts have been made to understand the production potential of pecan trees (Wood, et al., 1983; Gammon et al., 1963) and the management required to keep them in shape to perform good nut yield in a long term period; however, we have scarce data supporting the cultivar behavior on a long term pecan production, so we proposed the study of fourteen cultivars on a period of nine consecutive years to determine the yield performance during this period.

Materials and Methods

The experimental pecan orchard was planted in 1976 in a 100 trees/ha (10 x 10m) density; located in the 25° 25'north latitude and 102° 48'west length parallel. The experimental place is 1100 m above sea level and has a yearly average precipitacion of 217 mm/year. Mean yearly temperature is 20.5° C with extreme low temperatures of -5° C and a maximum of 41° C.

The orchard is irrigated frequently with an accumulated laminae of 1.2 m per year distributed mainly form March to September.

The pecan cultivars established for this study were: 'Caddo', 'Cape Fear' , 'Cherokee', 'Cheyenne', 'Choctaw', 'Mohawk', 'Frutoso', 'Shawnee', 'Shoshoni', 'Sioux', 'Tejas', 'Western Schley' and 'Wichita'.

Uniform evaluations on yield were taken since 1986 to 1995, considering a per tree basis, with 4 tree replicates. Nut yield is expressed as yield efficiency (YE), which is obtained by dividing the grams of inshell nuts by the trunk cross sectional area (TCSA) of the tree, measured at 40 cms above the soil on the main trunk.

Alternate bearing index (ABI) contemplates the total number of years harvested and was evaluated through the variation coefficient percentage (CV%), which is considered as a statistical value that includes the standard deviation divided by the mean value and multiplied by 100.

The interpretation is made on the basis that ABI values tending to zero% agree with low alternate bearing cultivars, and those having a tendency toward 100% ABI correspond to cultivars with high alternate bearing behavior.

For the long term production behavior of the pecan cultivars we calculated another value, which we called 'Long Term Productive Index' (LTPI). This is the average YE divided by ABI.

LTPI values tending toward one, correspond to the best cultivars while those with values tending to zero, are the cultivars with low stability in the long term production performance.

By selecting these indexes as discriminating criteria, we selected the most suitable pecan cultivars for the North-Central part of Northern Mexico.

Results and Discussion

Yield Efficiency:

The consideration of yield efficiency (YE) allows us to compare the productive potential of each cultivar along their life cycle; in this trial we observed high YE values in

cultivars such as 'Shoshoni', 'Cherokee' and 'Wichita', reporting productions of 173, 132, and 111 g/cm2 TCSA, indicating their ability to produce nuts early in their life cylce,. as it is indicated by Madden (1972); however , most of the cultivars showed their best YE during the first years of production (Table No. 1).

Pecan cultivars evaluated by their YE varied in nut production along the nine year evaluation periord, and most of the cultivars showed a low production by the year 1995, probably due to the fact that by this year the trees got crowded (Table No. 1).

Yield efficiency in nut prodution varied in the range of 10 to 51 g/cm2 TCSA; however, the YE fluctuation among years is very considerable resulting in the alternate bearing behavior of the pecan cultivars (Table No. 1).

Average YE for pecan cultivars during the first fifteen years of production reached up to 50 g/cm2 TCSA for 'Shoshoni'; however, it had a high productive variation during the nine year period from 173 g/cm2 to 2 g/cm2 TCSA. (Table No. 1).

Pecan cultivars presenting values from 30 to 40 g/cm2 TCSA were 'Western Schley' (40); 'Wichita' (40); 'Cherokee' (40); 'Frutoso' (36); and 'Shawnee' (32). Fluctuation on yearly production is evident; however this phenomenon is lower for the Western Schley cultivar (Table No. 1).

Another group of cultivars that behaved with lower average values of YE (18-28 g/cm2 TCSA) were: 'Choctaw' (28), 'Caddo' (21), 'Cape Fear' (20), 'Cheyenne' (22), 'Gratex' (21),'Tejas' (21),'Mohawk' (20), and 'Sioux' (18). These cultivars showed the lowest YE, therefore, they may not be considered as the production alternative to common planted cultivars (Table No.1).

Alternate Bearing Index (ABI)

Fluctuation of nut yield during a period of years is a good index to screen among pecan cultivars.

ABI fluctuated in this study from 38% in 'Cape Fear' to 105% in 'Shoshoni'.

Pecan cultivars with ABI lower than 60% during the nine year period were: 'Cape Fear' (38%), 'Western Schley' (43.9%), 'Tejas' (48.9%), 'Sioux' (50.5%) and 'Caddo (59.9%). This group of cultivars should be considered as good choices because of their low ABI.

The productive behavior of a group of pecan cultivars should consider more than one factor involved in production. Considering both YE and ABI as the two dominant factors expressed in the long term performance of a pecan cultivar, the pecan production index (LTPI) must be a good tool for discriminating and selecting more suitable pecan cultivars for a good stable yield and production in the long term (Table No. 2).

In the evaluation of fourteen pecan cultivars, LTPI values fluctuated from 0.91 for the best suited cultivar 'Western Schley'down to 0.31 for 'Mohawk'.

'Western Schley'was the only cultivar with an LTPI near to the value of 1, which indicates that no other cultivar has the ability to producre high yield of nuts and also to alternate at a minimum rate (Table No. 2).

The pecan cultivars 'Cape Fear'(0.52), 'Wichita' (0.53), and 'Shoshoni'(0.48) reported an LTPI from 0.45 to 0.55, so based on the same criterion, these cultivars are considered a good second choice for productive pecan cultivars in this region (Table No. 2).

Kernel Production

Kernel production in pecan cultivars is well defined as a genetic characteristic (Madden,1972). The values reported for this group of cultivars fluctuated from an average (9 years) of 62.5% for 'Wichita', to the lowest value of 47.1% for the 'Frutoso'cultivar (Table No. 3).

Analyzing the ABI calculated on kernel production basis, the values obtained are small, fluctuating from 1.9 for 'Western Schley'and 'Cheyenne', up to 11.3% for the 'Cape Fear'cultivar (Table No. 3).

We selected those cultivars with values equal or higher than 55% kernel:
'Wichita'(62.5%),   "Gratex   (61.6%),
'Shawnee'(58.8%),   'Mohawk   (59.9%)

'Sioux'(58.8%), 'Choctaw'(58.25), 'Western' (58%), 'Cheyenne' (56.7%), and 'Cherokee' (55%) (Figure No. 1).

Following the tendency of the cultivars being controlled by the genetic quality expressing the percentage of kernel, we should pay attention to the values required for selecting cultivars for specific regions and management's; such as Wichita and Western , two suitable cultivars for the North Central part of Mexico, based on the selection of LTPI and fulfilling the requirements to produce high percentage of kernel.

Figure No. 1 Nine Years Percent Kernel Reported for Fourteen Pecan Cultivars Grown in the North Central Part of Mexico. 1998 CELALA-INIFAP.

Selecting pecan cultivars out of one or two parameters may be insufficient to make a good choice for the long term productive yield of pecan nuts and their quality.

Since there is no easy way to establish these support parameters, and having into account the fact that pecan cultivars require to be evaluated in the long term, we proposed the ABI as a parameter that by itself involves first of all, several years of evaluations.

We could select with this parameter three cultivars out of fourteen having an ABI value lower than 50%: 'Cape Fear' (38%), 'Western' (43.9%) and 'Tejas' (48.9%); however, 'Western Schley' is the only one having the capability of producing a yield efficiency of 40 gr/cm2 TCSA (Table No. 4).

Due to the fact that we need to evaluate high producing pecan cultivars, and considering the stability of this yield along the life cycle of the pecan trees, we proposed the LTPI and using this parameter we selected the next cultivars: 'Western Schley' (0.91), 'Wichita' (0.53) and 'Cape Fear' (0.52).

The long term selection for pecan cultivars should use as many parameters as possible; we propose four: yield efficiency, percent of kernel, alternate bearing index and long term productive index. Considering these parameters, the only cultivar considered in this study is 'Western Schley' (Table No. 4).

'Western Schely' is the cultivar that has been planted in North Central Mexico occupying 70% of the improved cultivars from Mexico.

No other cultivar has the capability of 'Western' to consider it as a possible alternative.

'Wichita' is a cultivar that has good selective characteristics such as yield efficiency of 40 g/cm2 TCSA, and a LTPI of 0.53, which is good; although the ABI showed a non-selective value of 75% that indicates low stability in the every- year production.

Conclusions

The best suitable pecan cultivar for the North Central part of Mexico is 'Western Schley'.

'Western Schley'is the only cultivar out of fourteen studied with an LTPI of 0.91, ABI of 43.9%, percent kernel of 58% and yield efficiency of 40 g/cm2 TCSA.

'Wichita'is the second best choice cultivar having an LTPI of 0.53, ABI of 75%, percent kernel of 62.5% and a yield efficiency of 40 g/cm2 TCSA.

Table 1. Yields Efficiency of Fourteen Pecan Cultivars Evaluated During their first Nine Consecutive Years (1986-1995). CELALA-INIFAP. 1998.

Cultivar	Yield Efficiency (g/cm2 trunk cross sectional area)									(X) (g/cm²)	A.B.I. (%)
	1986	1987	1988	1989	1990	1991	1992	1994	1995		
Shoshoni	98	173	6	46	40	32	59	9	2	51	105
Cherokee	61	132	13	38	21	36	42	17	5	40	93.6
Wichita	49	111	26	24	40	41	48	23	2	40	75.0
Western	48	69	46	39	57	22	46	17	27	40	43.9
Frutoso	84	80	3	50	15	16	32	19	27	36	80.2
Shawnee	35	48	12	31	36	36	83	9	2	32	74.9
Choctaw	79	52	14	31	11	20	27	14	5	28	84.0
Caddo	36	28	24	3	36	28	24	6	7	21	59.9
Cheyenne	16	51	12	38	16	22	27	9	7	22	66.0
Gratex	45	32	9	15	28	33	21	7	5	21	63.6
Cape Fear	17	26	27	21	24	30	25	10	7	20	38.0
Texas	25	31	22	27	35	8	24	7	10	21	48.9
Mohawk	31	48	13	26	11	11	21	11	10	20	63.8
Sioux	18	22	17	17	24	36	22	8	5	18	50.5
Significance									N.S.		
C.V. (%)									83.7		

C.V. (%)- Variation Coefficient
A.B.I.- Alternate Bearing Index

Table 2. Nine Year Average Yield Efficiency and Alternate Bearing Index to Perform the Long Term Productive Index of Fourteen Pecan Cultivars in the North Central Part of Mexico. CELALA-INIFAP. 1998.

Cultivar	A.B.I.	Yield Efficiency g/cm² t.c.s.a.	L.T.P.I.
Cape Fear	38.0	20	0.52
Western	43.9	40	0.91
Texas	48.9	21	0.43
Sioux	50.5	18	0.36
Caddo	59.9	21	0.35
Gratex	63.6	21	0.33
Mohawk	63.8	20	0.31
Cheyenne	66.0	22	0.33
Shawnee	74.0	32	0.43
Wichita	75.0	40	0.53
Frutoso	80.2	36	0.45
Choctaw	84.0	28	0.33
Cherokee	93.6	40	0.43
Shoshoni	105.0	51	0.48

A.B.I.- Alternate Bearing Index
t.c.s.a.- trunk cross sectional area
L.T.P.I.- Long Term Productive Index

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Table 3. Nine Years Percent Kernel Reported for Fourteen Pecan Cultivars Grown in the North Central Part of Mexico. CELALA-INIFAP. 1998.

Cultivar	% kernel									(X)	A.B.I (%)
	1986	1987	1988	1989	1990	1991	1992	1994	1995		
Wichita	64.0	62.0	66.2	62.0	62.0	61.5	62.5	59.9	62.7	62.5a	2.9
Gratex	63.0	61.2	63.0	63.1	59.0	60.0	63.0	60.3	61.8	61.6a	2.6
Shawneee	62.0	58.2	61.2	57.0	58.0	58.0	58.0	59.9	58.1	58.8b	2.9
Mohawk	59.0	59.2	62.5	58.0	57.0	58.6	59.0	59.0	59.0	59.0b	2.2
Caddo	62.0	57.8	62.1	57.4	58.3	58.4	58.0	57.4	58.5	58.9b	3.2
Sioux	58.0	60.8	63.8	59.7	58.4	50.0	58.0	59.0	60.9	58.8b	6.4
Choctaw	58.0	58.3	59.9	61.0	57.6	57.5	56.5	58.2	57.0	58.2b	2.4
Western	58.0	56.1	60.2	57.4	58.6	58.5	58.0	57.2	58.7	58.0b	1.9
Cheyenne	57.0	55.8	57.6	57.7	58.0	57.0	57.0	54.5	56.7	56.7bc	1.9
Cherokee	58.0	53.3	56.4	52.5	56.0	56.0	55.0	56.3	51.9	55.0cd	3.7
Texas	56.0	54.7	57.6	54.1	55.3	55.0	54.0	51.8	54.4	54.7cd	2.9
Cape Fear	56.0	56.1	55.6	40.0	57.3	51.6	56.0	62.5	53.4	54.3d	11.3
Shoshoni	54.0	49.3	54.2	50.9	54.0	52.1	54.0	52.4	54.8	52.8d	3.5
Frutoso	51.0	44.2	48.9	40.1	56.0	46.0	43.7	46.6	43.9	47.1e	10.1
Significance									**		
D.M.S.									2.5		
C.V. (%)									4.71		

** P< 0.01

Table 4. Parameters Considered in the Selection of Pecan Cultivars for High Nut Quality and Yield on a Long Term Basis. CELALA-INIFAP. 1998.

CULTIVAR	Yield Eff.	% KERNEL	LTPI	ABI
ACCEPTABLE RANGE	>30	>55	>0,5	<50,0
sioux	18	58.8	0.36	50.5
cape fear	20	54.3	0.52	38
mohawk	20	59	0.31	63.8
tejas	21	54.7	0.43	48.9
caddo	21	58.9	0.35	59.9
gratex	21	61.6	0.33	63.6
cheyenne	22	56.7	0.33	66
choctaw	28	58.2	0.33	84
shawnee	32	58.8	0.43	74.9
frutoso	36	47.1	0.45	80.2
western	40	58	0.91	43.9
wichita	40	62.5	0.53	75
cherokee	40	55	0.43	93.6
shoshoni	51	52.8	0.48	105

ABI   Alternate Bearing Index
Yield Eff.   Yield Efficiency (gr /cm 2) trunk cross sectional area.
LTPI   Long Term Productive Index (Yield Eff. / ABI)

Figure 1.   Nine years percent kernel reported for fourteen pecan cultivars grown In
the North Central part of Mexico. CELALA-INIFAP. 1998.
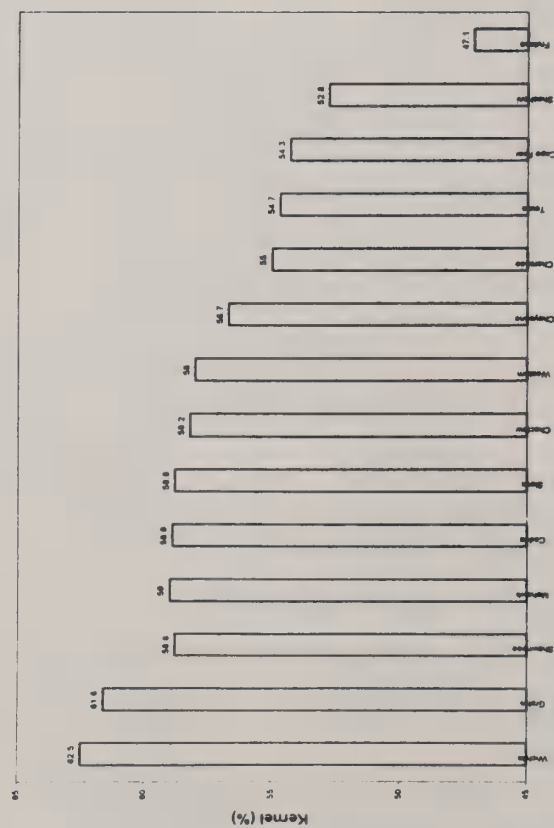
A COMPARISON OF DEGREE-DAY MODELS FOR PREDICTING PECAN NUT CASEBEARER

Mark Richer and Tim L. Jones[1]

Additional index words: Acrobasis nuxvorella, first nut entry, heat units, chill units

ABSTRACT

The pecan nut casebearer (PNC) has become a serious concern in Mesilla Valley, southern New Mexico. It is a potentially devastating insect to pecan trees that has long been a problem in Texas. Accurate predictions (e.g., day of year) of PNC life stages, particularly first significant nut entry (FNE), are essential to any successful operations designed to control damage to nut crops. Computer models, based on climatic parameters, have been effective in predicting PNC life stages in pecan-growing areas of the Midwest, Mexico, and Texas. The two most popular models use either heat degree-days (Texas model) or both heat and chill degree-days (Sparks model) to predict PNC development. This project uses historical weather data from various locations within the Mesilla and El Paso valleys to analyze model predictions, and where possible to compare predictions with actual field observations. The results indicate that the Texas model predicts a more consistent day of year (153 +/- 3) than the Sparks model (149 +/- 6) for FNE. This is probably attributable to the variability in winter "chill" accumulation from year to year in the region. The Sparks model is more sensitive to changes in temperature averaging methods, and preliminary data suggests that the Sparks model more accurately predicts observed FNE than the Texas model.

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Texas pecan growers have long considered the pecan nut casebearer (PNC) to be their major insect threat (Thomas and Hancock 1968; Harris 1998). It has also long been understood that in order to exercise control over PNC crop damage, one must anticipate the stages of the insect's life cycle (Gill, 1917; Bilsing, 1926). There are very narrow windows of opportunity to control this pest by chemical and non-chemical (i.e. *B. thuringiensis*) means. Previous research has repeatedly shown that, of all the PNC's stages, the first summer generation larvae are the most damaging. Effective management requires control of these larvae prior to nut entry (Bilsing 1926; Davis 1995; Gill 1917; Sparks 1995). There are no systemic insecticides for PNC, therefore the first generation's larval stage must be targeted during the two to three day feeding stage between egg hatch and nut entry (Knutson and Ree, 1995; Sparks 1995). Insecticides, if necessary, are applied at first significant nut entry (FNE), two or three days after first summer generation eggs hatch. Nut entry is considered significant when about 1% (Sparks, 1995) or 1 to 3% (Ring, 1981) of nut clusters inspected have been entered by PNC larvae.

Several methods for predicting when a damaging PNC population will occur have been devised and implemented over the years. Historic methods include: relying on empirically determined calendar dates, field observations of moth emergence or first nut entry, or on pecan phenology (e.g., waiting for the tips of the nutlets turn brown) (Ring, 1981; Sparks, 1995). Predictions were later augmented by monitoring PNC pupation and

adult emergence using banding and blacklight traps (Bilsing, 1927; Ring and Harris, 1983; Sparks, 1995; Thomas and Hancock 1968). Each of these methods have drawbacks: key dates in PNC phenology vary by locality and from year to year (Gill, 1917; Ring, 1981), constant scouting is prohibitively labor intensive and time consuming, aspects of pecan phenology differ between varieties (Ring, 1981), blacklight traps collect non-target insects, and banding may not catch enough larvae to accurately time treatments (Thomas and Hancock 1968).

In recent years, as the technology became more available, computer models for predicting life cycles of agricultural pests have grown in popularity and accuracy (Mowitz and Peterson 1997). The first predictive PNC model, based on daily ambient air temperatures, was developed by Ring and Harris at College Station, Texas in the early 1980s (Ring and Harris 1983). The Texas model assumes the PNC life cycle, including FNE, can be predicted from ambient spring air temperatures. About fifteen years later, Darrell Sparks at the University of Georgia developed a second computer model for predicting FNE (Sparks 1995). The Sparks model is also based on ambient air temperatures, but includes winter as well as spring temperatures. The contemporary development of the Internet offers easy and often free access to local weather data, making such models practical for major and gift-of-nature producers alike.

Systematic investigations of the PNC are just beginning in the Mesilla Valley of New Mexico and the El Paso Valley of Texas, so observational experience with FNE in the region is scarce. The purpose of this project is to apply both the Texas and Sparks models of PNC development to these areas.

Computer code was created that implements both models. Historical weather data, in particular average air temperature, was used to estimate the average day of year and ranges of calender days where FNE is most likely to occur. The results were compared against the sparse amount of available field data.

MODELING METHODOLOGY

The Texas and Sparks models base their predictions of PNC development on the temperatures experienced by the insect population over time. The degree-day is the unit that combines temperature and time, and can be used to account either for heating or chilling. One heat degree-day is accumulated for each degree the daily average temperature is above the selected base temperature and one chill degree-day is accumulated for each degree the daily average temperature is below the selected base temperature. The degree-day is commonly referred to as a measure of physiological time.

The procedure for calculating cumulative degree-days is:

$$^{o}D = \sum_{i=1}^{n} (Ta - Tb)_i \quad [1]$$

where ^{o}D is the degree-days accumulated between day 1 and n, T_a is the average daily temperature, and T_b is the base temperature. Degree-days calculated using the centigrade scale are five-ninths as big as degree-days calculated using the Fahrenheit scale. Metric units are used in this study.

The calculation of T_a for the original Texas and Sparks models was done by simply

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adding the daily minimum air temperature to the daily maximum air temperature and dividing the sum by two:

$$T_a = \frac{(T_{max} + T_{min})}{2} \quad [2]$$

where T_{max} is the daily maximum air temperature, and T_{min} is the daily minimum air temperature. Until recently, daily minimums and maximums were the only air temperatures reported by most weather services in the United States. This has therefore been the *de facto* method of figuring daily average temperatures.

With the advent and availability of automated electronic equipment, methods of climate data collection are changing. At all New Mexico weather network stations climate data is collected by Campbell dataloggers that measure air temperature at ten-second intervals, from midnight to midnight. The reported daily average is the numerically integrated average of those readings:

$$T_a = \sum_{i=1}^{n} \frac{T_i}{n} \quad [3]$$

Where n is the number of temperature readings taken in a day: 8 640 ten-second readings. This method of averaging more accurately reflects the true average temperature.

These degree-day models require the selection of a start date to begin the accumulation of heating or chilling degree-days, and a base temperature for Eq. [1]. Ring and Harris (1983) used PNC field data collected by Bilsing (1926; 1927) to correlate the insect's life stages with accumulated heating degree-days. Sparks

(1995) obtained field data from a variety of sources to evaluate the correlation of FNE with the interaction of heating and chilling.

The Texas model. The Texas model (Ring and Harris 1983), originally designed for the College Station, Texas region, uses a start date of 12 March and a base temperature of 3.3°C. Based on historic PNC and weather data, the model predicts that the first overwintering generation adults appear after the accumulation of 750.2°D, and FNE occurs at 1017.3°D.

The Texas model is generalized for use in locations outside College Station by modifying the start date according to the number of frost-free days (FFD) in the region. One day is added or subtracted to College Station's start date (12 March) for every 2.72 fewer or greater FFD a region has compared to College Station (Ring et. al. 1983). This presents a problem for Mesilla Valley, where the length of the frost free season is more variable than that of College Station. A regional (non-weighted) average of 211 frost free days was used.

The frost-free period is sometimes called the "freeze-free" season (NOAA 1994) or the "growing season" (Kunkel 1985). It is defined as "the mean number of days between the mean date of last spring freeze (0°C) and mean date of first fall freeze" (Ring et. al. 1983; pg. 489).

Sparks Model. The Sparks FNE model (Sparks 1995) is a modification of Sparks' earlier pecan budbreak model (Sparks 1993), which predicts budbreak based on the interactive effects of chilling (or rest) in the winter and heating in the spring. The Sparks model accumulates chilling units from 1 December through 28 February, and uses a heating start date of 1 February. The base

temperatures are 9.4 and 13.9°C for chilling and heating respectively.

The number of heating units required for FNE to occur is predicted from the quantity of chilling units accumulated. The equation used to evaluate the combination of chill and heat is:

$$1/Y = 0.0037259$$
$$[1 - 0.1e^{-0.0028069(x - 574.9638969)}] \quad [4]$$

where $1/Y$ is the heat accumulated from 1 February until FNE, e is the exponential function, and x is the accumulated chill.

Weather data. Weather data was obtained from two sources. The majority was downloaded from the New Mexico State network's free internet service (http://weather.nmsu.edu). All networked Hatch and Mesilla Valley stations were examined, and all available data for those stations was used. They are Berino, Derry, East Mesa (NMSU golf course), NWS Las Cruces (police station), the Fabian Garcia Horticultural Experimental station (FGHF), the Jornada Experimental Station, and the Leyendecker Plant Science Research Center (PSRC).

Two weather stations from the national cooperator network (operated by the National Climate Data Center, or NCDC) were also used: the El Paso Airport station and the State University station in Las Cruces, New Mexico. El Paso data came from two different sources: January 1948 through December 1996 from the free internet service (http://climate.usu.edu) provided by Utah State University, and data for 1997 and 1998 from the El Paso National Weather Service internet site (http://nwselp.epcc.edu) on the Rio Grande

Freenet. Las Cruces data also came from two different sources: April 1959 through 1992 from a CD-ROM available from the NCDC, and January 1994 through 1997 also available at the Utah State University site. The weather stations are summarized in Table 1.

PNC data. Rigorous model verification is difficult because very little PNC data is available for Southern New Mexico and El Paso. The available data was not consistently gathered (i.e. collected in the same manner and from the same location from year to year) and must therefore be used with caution.

Jim Davis (1995) made available pheremone trap data from a 1994 study conducted in the El Paso area. 1995 pheremone trap data was obtained from the Texas A&M extension office in El Paso. Tracey Carillo provided pheremone trap data collected in 1997 on Stahmann Farms in Mesilla Valley.

Ring and Harris (1983), in their examination of historic PNC data, found a strong correlation between first significant nut entry and 65% emergence of the overwintering generation. Pheremone traps only capture male adult moths, and the female segment of the population emerges about 3 days after the males (Ree 1998). Other research (Ree 1998) shows nut entry to occur 12 to 16 days after the first males are trapped. These interpretations are consistent and both considered good first approximations. Model predictions were evaluated accordingly.

RESULTS AND DISCUSSION

Temperature averaging. Running the model with numerically integrated average

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temperature input, Eq. [3], predicted earlier FNE than when the model was run with temperatures calculated by averaging daily maximums and minimums, Eq. [2]. This effect is much more pronounced for the Sparks model. Evaluating the Sparks model for a fifteen year period at PSRC, FNE predictions using Eq. [3] range from 2 to 12 days earlier (mean = 6.9) than predictions for the same time period using Eq. [2]. Figure 1 illustrates the effect choice of temperature averaging has on FNE prediction, and Figure 2 shows how the methods compare on a day-by-day basis.

The Texas model is less sensitive to the substitution of Eq. [2] for Eq. [3]. In the same scenario, Texas model predictions run from a day earlier to five days later (mean = 2.3 days later).

Frost-free days. Table 2 summarizes average FFD, as calculated at each weather station. The variability is evident in the standard deviation, which is typically 20 to 30 days (the one exception, Derry, is based on only two years' data).

First significant nut entry predictions. Sparks FNE model predictions are consistently earlier than those of made by the Texas model, excepting springs following warm winters. 1994 was an unusually warm winter in the Mesilla Valley, so for many stations the Texas model predicted an earlier FNE for 1995. Figure 3 depicts how the two models differ, over a period of 50 years in El Paso.

Analyzing by weather stations, the standard deviation of the day of FNE is two to three times greater for Sparks model predictions than for the Texas model predictions. This results in calendar ranges for FNE (based on three standard deviations) of 14 to 23 days

for the Texas model, and 9 to 57 days for the Sparks model, depending on the weather station. The averages and expected ranges for FNE are summarized in Table 3 by weather station.

Based on the limited PNC data for the region, it appears both models tend to predict FNE later than observed. The Sparks model appears, consistently, to be more accurate. Available data points compared with relevant model predictions are recounted in Table 4.

CONCLUSIONS

Because of the scarcity of consistently gathered PNC data at this time, explicit judgements regarding the models' accuracy for the region are impossible. Tentatively, the Sparks model FNE predictions appear to be more accurate than the Texas model. It is possible that customizing the Texas model for the arid southwest, by reparameterization or by an improved estimation of FFD, will ameliorate its accuracy.

A common, and often valid, complaint regarding the PNC models is that they are unreliable, or inconvenient. These criticisms are sometimes true. There is, however, an interplay when constructing or working with agricultural models between wanting to provide a simple product that is useful to producers, and gaining insight into the system under consideration, in this case the behavior of the PNC in the Doña Ana County region.

The process of trying to model such systems is often helpful in quantifying the influence of variables, or in identifying previously unnoticed relationships and gaps in knowledge. A detail that currently has researchers and pecan growers puzzled in the

desert southwest is: Why hasn't the PNC become a problem? It is listed by East Texas growers as their major pest concern, yet after at least six years in the Mesilla Valley the PNC has not been seen to cause significant damage. Why not? The answer is likely to lie in environmental or climatic differences, or both. A better understanding of model parameters like base temperatures, FFD, and heat and chill units will doubtless lead to improvements in PNC control, and in pecan management generally.

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Figure 1. Sparks model predictions of first significant nut entry for PSRC, using two methods of temperature averaging

Legend: ■ (Tmin + Tmax) / 2   ▶ numerically integrated
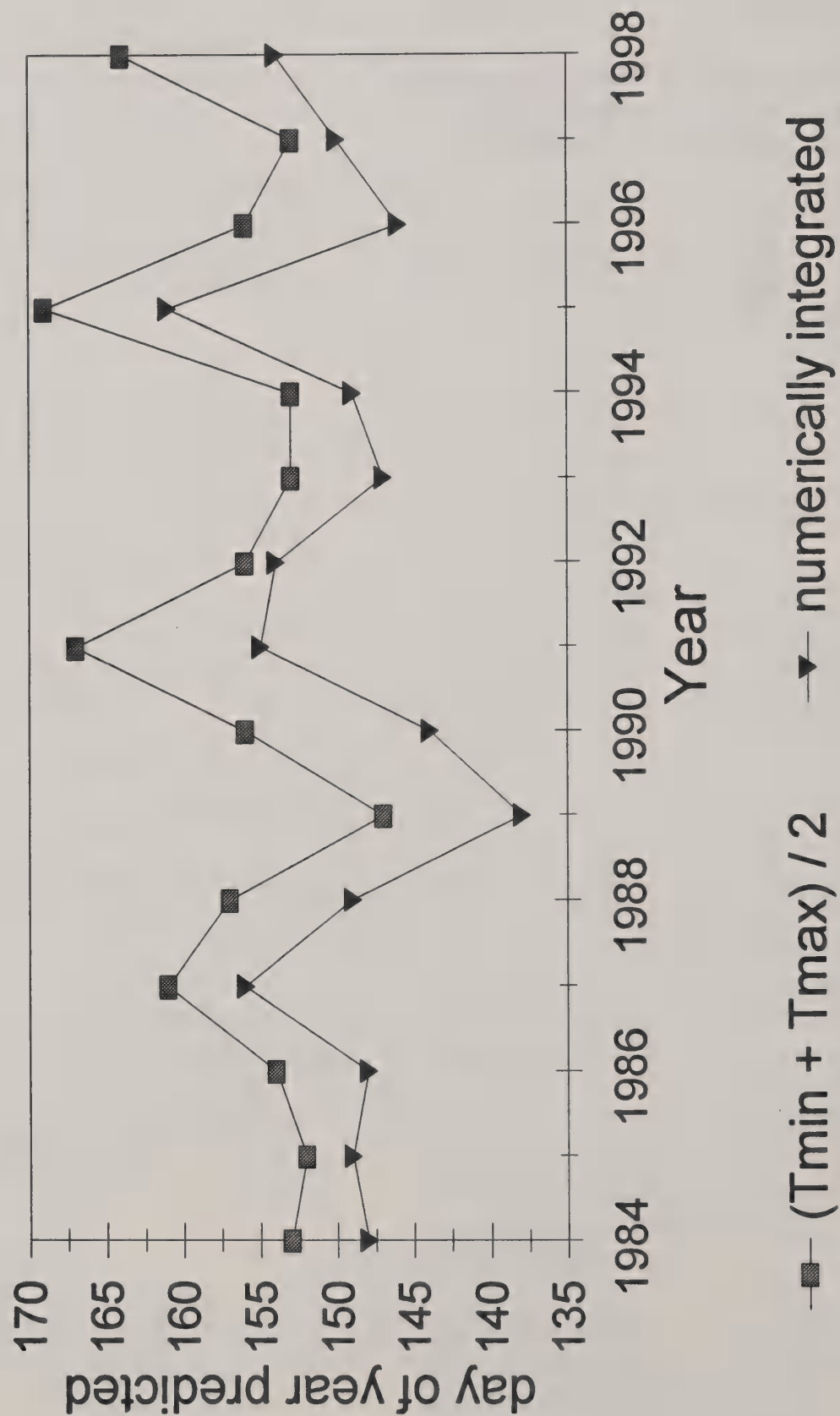
Figure 2. Temperature averaging methods compared for PSRC, month of May 1996.
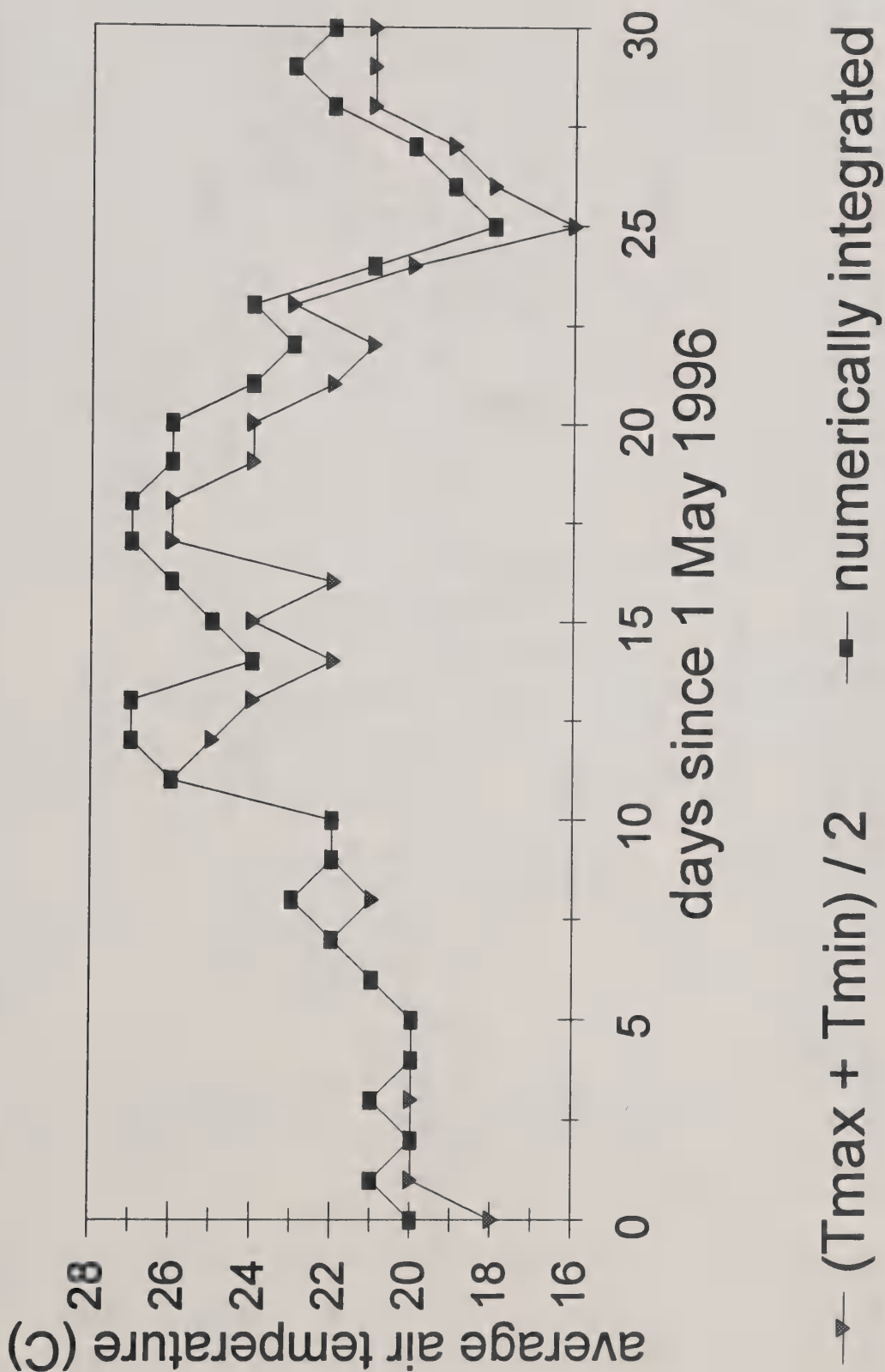
Figure 3. Predicted first significant nut entry at El Paso. Texas and Sparks models compared, with known data points included.
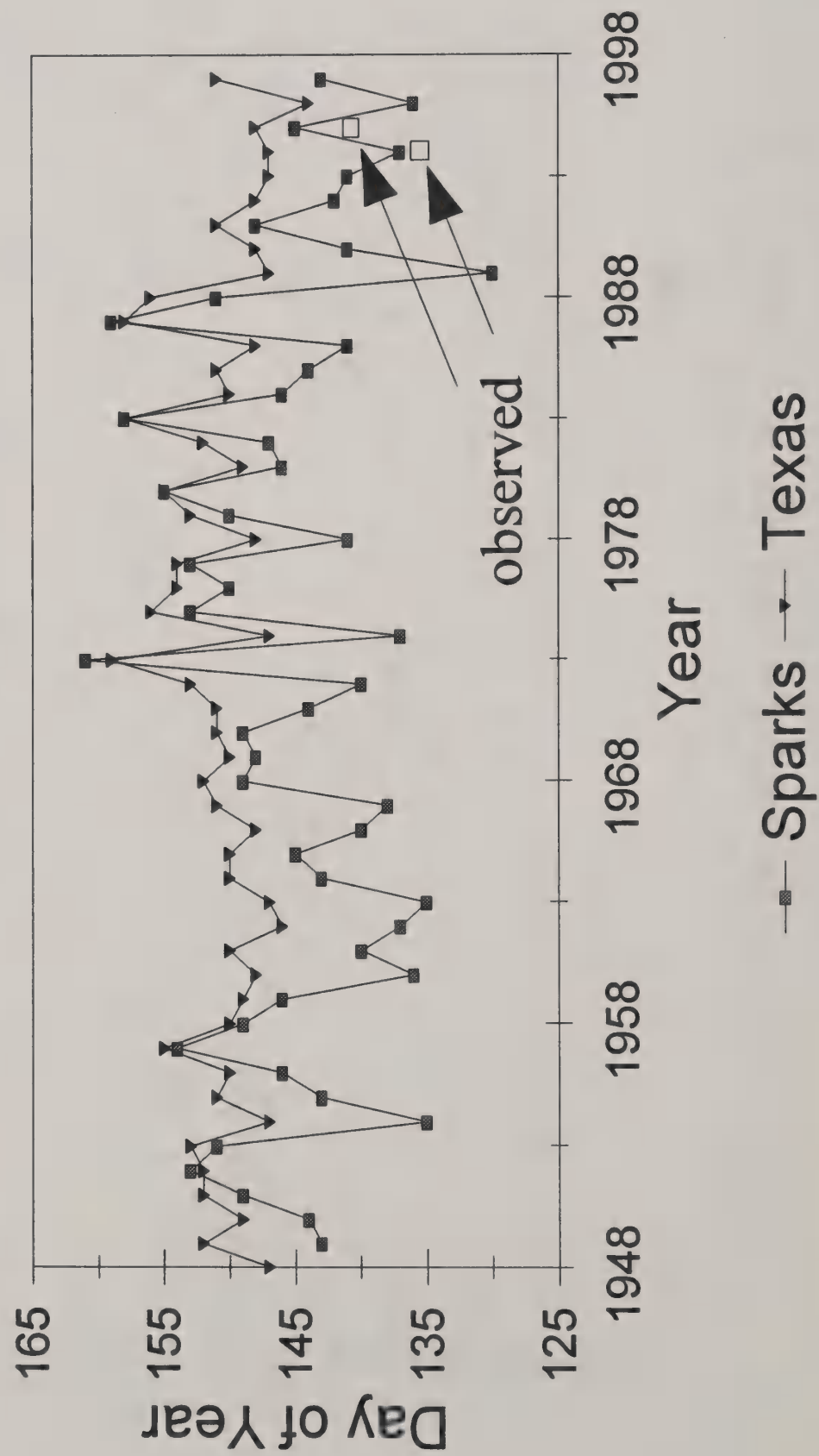
Table 1. Summaries of weather stations

Station	Location	Lat.	Lon.	Elev. (m)	Environment
Berino	Two miles west of Berino on route 478	32° 03' 50.4"N	106° 40' 12"W	1147	Bare soil for 25 feet, crop cover to the north and west, trees and buildings to the south and east
Derry	Derry, West of I-10 highway	32° 47' 47.2" N	107° 17' 9.6" W	1255	Sand for 50 ft, then crop cover
NWS, Las Cruces[a]	South-central Las Cruces, on NMSU campus	32° 16' 56.0" N	106° 45' 35.9"W	1183	Grass cover for 100 feet, then asphalt to the east, bare soil and buildings west and south, crop cover to the north
State U; National Weather Service, Las Cruces	South-central Las Cruces, on NMSU campus	32° 16' 56.0" N	106° 45' 35.9"W	1183	Grass cover for 100 feet, then asphalt to the east, bare soil and buildings west and south, crop cover to the north
Fabian Garcia Horticultural Experimental St.	Two miles east of Mesilla; southern outskirts of Las Cruces	32° 16' 43.02" N	106° 46' 15.6"W	1183	Grass cover for 25 feet, then crop cover
Jornada Experimental St.	25 miles northeast of Las Cruces	32° 31' 17" N	106° 47' 50" W	1359	Range land, mostly grass and shrubs
Leyendecker Plant Science Research Center	15 miles south of Las Cruces	32° 12' 4.44"N	106° 44' 32.88"W	1168	Grass cover for 25 feet, then crop cover
East Mesa	On NMSU's Golf course	32° 17' 4.44"N	106° 43' 54.78"W	1265	Grass surrounded by golf course
El Paso airport	until 1995, EPIA; after 1995, Santa Teresa NM	31° 48'N	106° 24'W	1062	

a). Though named "NWS," this station is actually maintained by the New Mexico state network. The reason for the name is that it is located next to the actual NWS weather station (State U, above). Hence both stations have the same latitude, longitude, and elevation.

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Table 2. Frost-free (FFD) day averages and standard deviations (sd)

Station	Avg. FFD	SD	Years of data
Derry	194	8.48	2 (1996 - 1997)
East Mesa	203	25.47	7 (1991 - 1997)
El Paso	232	21.35	50 (1948 - 1997)
Fabian Garcia	206	38.06	10 (1988 - 1997)
Jornada	212	24.37	7 (1991 - 1997)
NWS - Las Cruces	225	21.02	7 (1991 - 1997)
State U. - Las Cruces	210	20.44	37 (1960 - 1997; missing 1993)
Plant Science Center	198	31.97	15 (1983 - 1997)
Average	210	23.89	

Table 3. Summary of first significant nut entry averages and ranges, according to weather station.

Station	Years of data	Day of year ± sd		Mean (± 3 sd)	
		Texas	Sparks	Texas	Sparks
Berino	2	151.5 ± 2.1	146.0 ± 1.4	May 25 - Jun 7	May 22 - May 30
East Mesa	7[A]	153.7 ± 2.6	151.7 ± 6.1	May 26 - Jun 10	May 13 - Jun 19
Fabian Garcia	11	151.8 ± 3.0	145.3 ± 9.4	May 23 - Jun 10	Apr 27 - Jun 22
Jornada	8[A]	150.4 ± 2.9	145.1 ± 5.9	May 22 - Jun 8	May 8 - Jun 12
NWS (Las Cruces)	8[A]	152.1 ± 3.2	148.7 ± 5.2	May 23 - Jun 11	May 13 - Jun 13
PSRC	16[A]	154.4 ± 3.9	149.9 ± 5.5	May 24 - Jun 14	May 13 - Jun 15
State U.	37[A]	156.9 ± 3.7	157.3 ± 6.9	May 26 - Jun 17	May 17 - Jun 27
El Paso	50[A]	150.7 ± 3.3	145.1 ± 6.8	May 21 - Jun 10	May 5 - Jun 14

A) indicates that for the Sparks predictions there is one less year with which to make estimates, because Sparks prediction requires data from the preceding year.

Table 4. Observed first significant nut entry, interpreted from trap data, compared with Sparks and Texas model predictions.

Station and year	Sparks	Texas	FNE, based on trap data
El Paso - 1994	May 17 (137)	May 27 (147)	May 16 (136)
El Paso - 1995	May 25 (145)	May 28 (148)	May 20 (140)
PSRC - 1997 (Stahmann)	May 30 (150)	Jun 4 (155)	May 26 (146)
FGHF - 1997 (Stahmann)	May 26 (146)	Jun 2 (153)	May 26 (146)

SIMULATION OF LIGHT INTERCEPTION IN PECAN TREES

Jose Ernesto Frias-Ramirez[1], Vincent P. Gutschick[2] and Tim L. Jones[3]

Additional index words. Foliage density, light interception, solar zenith, solar azimuth

ABSTRACT

Light interception by the pecan tree canopy is closely related to water use efficiency and productivity. The amount of light intercepted by a tree canopy in a certain location and a certain time depends on the canopy structure, orchard design and solar position. Field research to optimize light interception and productivity per ground area is too expensive and time consuming. Therefore, computer models have been developed as an alternative way to describe and design the canopy-light process. A computer model was constructed to simulate light interception in pecan trees considering direct and diffuse radiation, orchard location, time of the year, foliage density, tree size and orchard geometry. The computer model accounts for solar positions as well as positions within the canopy. It simulates different percentages of canopy closure to estimate the average fraction of diffuse and direct light intercepted by the tree canopy. The calculation is based on the Beer-Lambert law considering a constant light extinction coefficient, uniform foliage density, spherical canopy shape, and random leaf angle distribution. The computer model requires as input data: orchard latitude, date in Julian days, foliage density, tree spacing and distance between rows of trees. The model outputs are: average light interception (mole/m^2s), total leaf area (m^2), total light intercepted per tree (mole/s), total light intercepted per crown area (moles/m^2s) and total light intercepted per ground area (moles/m^2s). The foliage density used for model simulations was measured in the field during 1996 and 1997 in commercial pecan orchards. Simulations for June 19, were performed for a pecan orchard located in Las Cruces, NM with foliage density of 1.3 (m^2/m^3) with three different planting densities. The results show that light interception per tree increases as the size of the tree increases. The amount of light intercepted per crown area slightly decreases as tree size increases. Light intercepted per ground area linearly increases as the size of the tree increases. However, light intercepted per ground area does not change with changes in the size of the tree after canopy closure. A validation strategy is being developed to compare the model estimates with direct measurements of light interception in pecan trees.

INTRODUCTION

Photosynthesis and dry matter production in pecans is largely dependant on light interception by the tree canopy. Light incidence and adsorption influence transpiration via canopy and leaf temperature and water vapor exchange between the leaves and the surrounding atmosphere. Therefore, the amount of light intercepted by a tree canopy plays an important role in the yield and water use efficiency of pecan trees (Johnson and Lakso, 1991).

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Light interception is a function of canopy structure, orchard geometry, solar position and tree size. Canopy structure is defined as the size, shape, distribution and foliar orientation of all above ground organs of a tree (Campbell and Norman, 1989; Hilbert and Messier, 1996; Herbert, 1991; Stoskopf, 1981; Sornprach, 1997). Orchard geometry is described by the spatial arrangement of trees given by tree spacing, distance between rows of trees and orientation (Rom, 1991). Solar position depends on latitude and longitude of the tree's location, time of the year and time of the day. The solar position is characterized by the zenith and azimuth angle of the sun (De Pury and Farquhar, 1997; Stoxkef, 1981; Herbert, 1991; Sornprach,, 1997).

An additional factor is determining light interception is tree shading. The amount of shading, is determined by the relation between tree size and orchard geometry. As trees in an orchard grow, their canopies begin to overlap. This causes shading which decreases light penetration and photosynthesis, affecting the health of canopy elements and ultimately tree production (McEachern, 1990)

Understanding light interception in relation to tree size and orchard geometry may help to find the optimum orchard geometry. Understanding light interception is also the first step in predicting light absorption which is key to predicting photosynthesis. Field research in pecans is expensive and takes many years to give results. In addition light interception measurements are difficult and time consuming and require sophisticated equipment to get reliable values (Middleton and Jackson, 1989).
An alternative way to understand light interception in orchards is simulation by computer models. The most common approaches are whole canopy models, canopy section models and canopy layer models.

(Norman and Wells, 1983; Johnson and Lakso, 1991) The last approach has been considered as the most accurate to describe the light canopy process.

OBJECTIVES

The purpose of this paper is to present preliminary results from a computer model constructed to simulate light penetration in pecan tree canopies. This model represents a multi-layer approach to simulate light interception in pecan orchards considering direct and diffuse radiation, time and location of the orchard, foliage density, tree size and orchard geometry. The model will be used to provide insight into tree size orchard geometry interactions as well to support the development of a pecan tree photosynthesis model.

THEORY

Light interception by foliage is defined as the amount of light reaching a leaf at a certain point within the canopy. The total amount of light is divided into two quantities: direct and diffuse. Direct light has reached the leaf by penetrating the canopy in a direct line from the sun, without being deflected or adsorbed by any other canopy element. Diffuse light is scattered light that reaches the leaf from all other angles. Light penetration depends on foliage density, fraction of leaves projected toward the sun beam and the path length of the radiation beam into the canopy. This process has been considered analogous to the transmittance of light through a solution described by the Beer-Lambert law (Anonymous, 1991; Campbell and Norman, 1989; Johnson and Lakso, 1991; Normand and Wells, 1983; De Pury and Farqhuar, 1997). The average fraction of light penetration (ratio of light intensity, I_i; to light intensity outside the canopy, I_o) in an array of

tree canopies has been estimated by the following equation (Normand and Wells, 1983).

$$P = \exp(-k\rho_f S)$$

where :

P = fraction of light penetrating a certain point within the canopy (Ii/Io)

k = light extinction coefficient

ρ_f = foliage density (m²/ m³)

S = light path length in canopy (m)

MODEL DESCRIPTION

A computer model was constructed based on the previous equation to simulate daily average light interception under conditions of constant incident direct light, and constant diffuse light. In addition of the incident light assumed, several variables are needed: the light extinction coefficient, the foliage density, orchard latitude, tree spacing, tree size and day of the year.

Several assumptions were used to construct this computer model. The tree canopy was considered to be spherical. The foliage density was considered to be uniform within the canopy. A random leaf angle distribution and a constant light extinction coefficient were also assumed. The radius of the tree was considered to be the top side of the orchard. Finally, light penetration was assumed to obey the Beer -Lambert law (Norman and Wells, 1983; Pierce and Running, 1988; Smith, 1991; Wells 1991; Norman and Wells 1991; De Pury and Farqhuar, 1997).

The total path length of light is calculated by the computer model from simulations of solar and canopy positions. Two different calculations routines are used to estimate the path length of light: one for diffuse light, and another for direct light. Five solar zenith

angles are combined with five solar azimuth angles to get twenty five solar positions per day for the diffuse light routine. For direct light, the path length of the radiation beam is calculated from the simulation of nine solar positions during the day (sunrise to sunset).

The computer program calculates six radial distances as fraction of tree spacing simulating foliage covering from 20 to 80% of the canopy closure (canopies touching each other). It estimates the light intercepted in six canopy layers of equal volume. One thousand points are picked by the computer within the canopy for a single tree. Then the path length of light traveling toward each canopy position is calculated. Up to 36 neighboring trees are also searched to find if they were in the path of the light beam, and affect the path length calculation. The total path length of the light ray is the sum of all trees' path lengths. The model calculates the mean fraction of light penetration for diffuse and direct light for each position selected within the canopy. The mean light penetration is calculated as the incident diffuse light times the mean fraction of diffuse light penetration, plus the incident direct light times the mean fraction of direct light penetration.

MODEL OUTPUTS

The computer model outputs for an specific location and a certain time simulation are: Average light interception (mole/m²s), Total leaf area (m²), Total light intercepted per tree (mole/s), Total light intercepted per crown area(moles/m²s) and Total light intercepted per ground area (moles/m²s)

SIMULATION PROCEDURE

Simulations of light interception for a pecan orchard located in Las Cruces, NM (Latitude 32.5) for June 19th (day 170) was performed

for three orchard planting densities: 9X9, 12X12, and 15X15 meters. Average values of direct light incidence (1.0 mole/m²s) and diffuse light incidence (0.30 mole/m²s) were used for the simulations. The light extinction coefficient was taken as a constant value of k=0.5 (Pierce and Running, 1988; Smith, 1991).

The foliage density defined as the square meters of leaves per cubic meters of canopy volume, was measured in commercial pecan orchards during 1996 and 1997 (Wells, 1991; Normand and Wells, 1983 and1991). During 1996 the foliage density was measured in a 28 years old Barton pecan tree in Berino, NM, and in 1997 it was done in a 35 years old Ideal pecan tree in San Miguel, NM. An average value of foliage density of 1.3 m²/m³ was estimated and used for the simulation procedure. The foliage density measurements were done using the plant canopy analyzer LAI-2000 (Wells and Normand, 1991). The field of view of the LAI-2000 was reduced to a ninety degree by placing a plastic cap on the sensor to take readings in four quadrants per tree (north, east, south and west). Two sets of readings (above and below canopy) were taken for each quadrant and tree, using the method for isolated plants with an asymmetrical canopy (Anonymous, 1992). The above canopy readings were taken outside of the orchard for 1996 and on top of the tree canopy by using a cherry picker machine in 1997.

RESULTS

The simulation results are summarized in table 1. Total light intercepted per tree (mol/s) was observed to increase as the size and spacing of trees increased (Figure 1). More leaf area is present in bigger trees which results in better surface coverage and light interception. For trees of equal canopy diameter, more light intercepted per tree was observed when the tree spacing was larger. For example, in an orchard with tree spacing of 9 m, an increment in tree canopy radius from 3.6 m to 4.5 m (25%), will increase the amount of light intercepted per tree by 38%. For trees of same size (4.5 m) an increase of tree spacing from 9 to 15m will increase the amount of light intercepted per tree in 28%. This may be a result of less shading with more space between. Mean light intercepted per crown area (mole / m² s) showed a trend to decrease as the size of tree increased (Figure 2). This effect was greater in trees of seven or more meters in canopy diameter. However, for the same canopy closure, more light per crown area was intercepted in trees of a larger size. The highest light interception per crown area was observed when the diameter of the trees were 500 % or 60% of tree spacing (30% canopy closure). Reductions from 7% to 18% of light intercepted per crown area were observed when canopy closure increased from 64% to 80%. Light interception per ground area showed a linear increased as the size of the tree increased, (Figure 3). Light intercepted per ground area did not change with changes in the size of the tree after canopy closure occurred. There was no difference in light interception per ground area, when covering the land with many small trees or covering the land with fewer big trees.

CONCLUSIONS

From the simulations results Larger trees intercept more light per tree. Larger trees intercept more light per tree and per crown area than smaller trees at the same percentage of canopy closure. Light interception per crown area decreases when close canopy occurs. Larger trees appear to have larger maintenance costs per crown area, that may offset increased light intercepted.

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Table 1. Results of light interception (LI) simulation for June 19, for a pecan orchard in Las Cruces, NM with tree foliage density of 1.3 m^2/m^3 and tree spacing of 9, 12 and 15 meters.

| Tree radius (m)	Tree spacing (m)	Leaf Area (m^2)	LI per tree (mole/s)	LI per crown area (moles/m^2s)	LI per ground area (moles/m^2 s)
2.25	9.0	62.0	32.6	2.1	0.4
2.70	9.0	107.1	47.8	2.1	0.6
3.15	9.0	170.2	64.5	2.1	0.8
3.60	9.0	254.0	82.6	2.0	1.0
4.05	9.0	361.7	99.7	1.9	1.2
4.50	9.0	496.2	115.2	1.8	1.4
3.00	12.0	147.0	62.8	2.2	0.4
3.60	12.0	254.0	90.8	2.2	0.6
4.20	12.0	403.4	121.3	2.2	0.8
4.80	12.0	602.2	154.1	2.1	1.1
5.40	12.0	857.4	184.3	2.0	1.3
6.00	12.0	1176.2	211.2	1.9	1.5
3.75	15.0	287.1	102.7	2.3	0.5
4.50	15.0	496.2	147.1	2.3	0.7
5.25	15.0	787.9	185.5	2.3	0.9
6.00	15.0	1176.2	247.3	2.2	1.0
6.75	15.0	1674.7	294.0	2.1	1.3
7.50	15.0	2297.2	335.4	1.9	1.5

Figure 1. LIght Interception per Tree
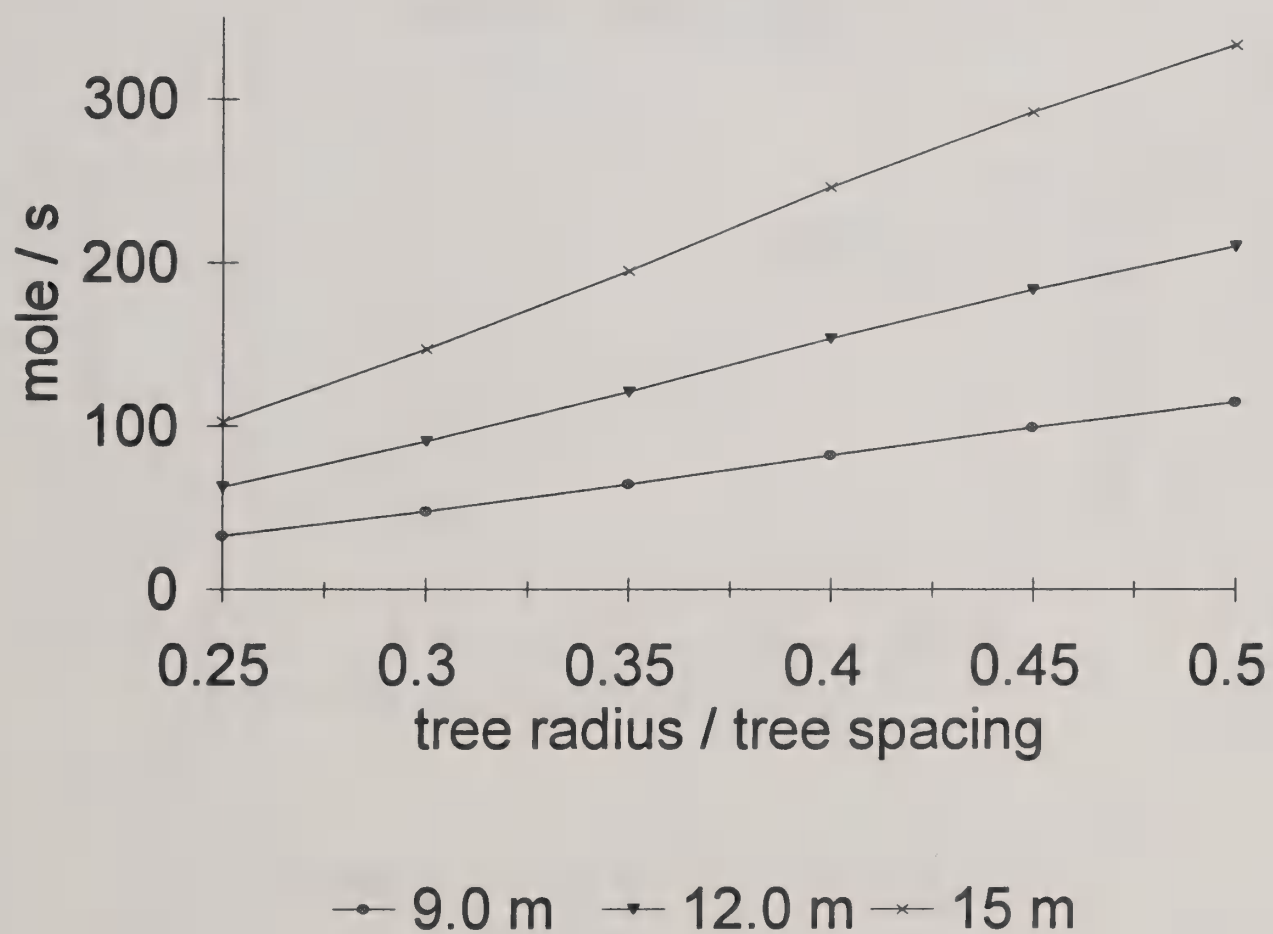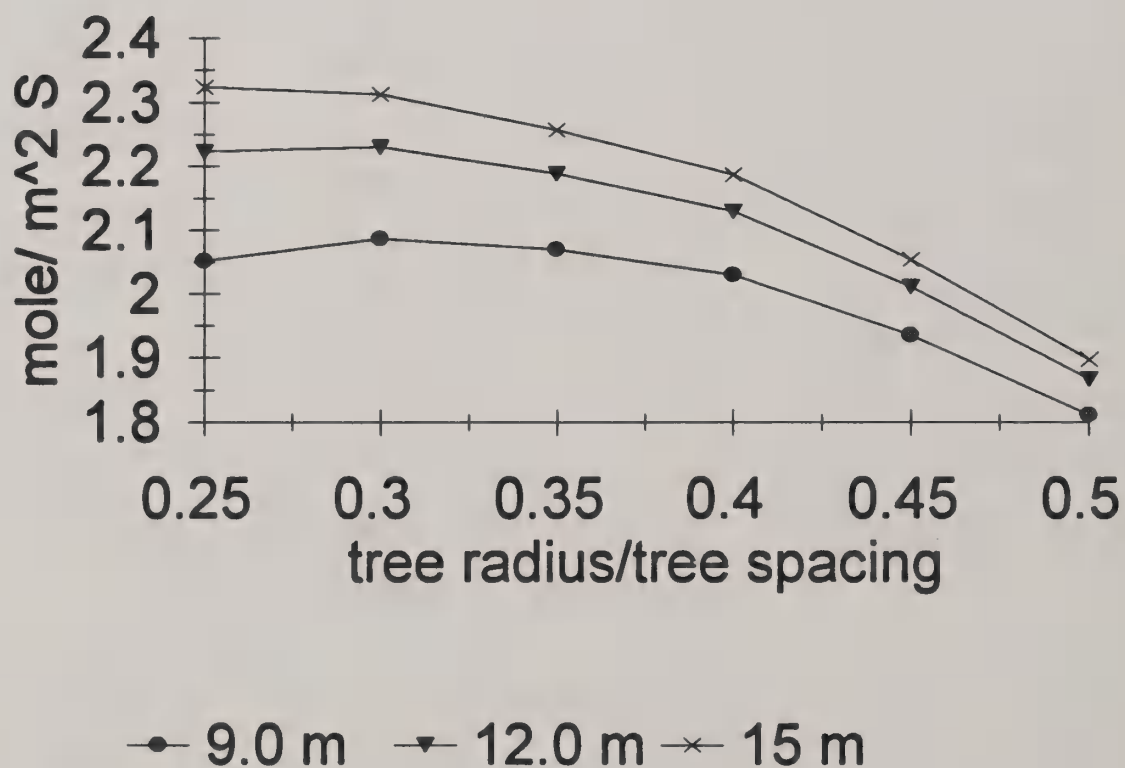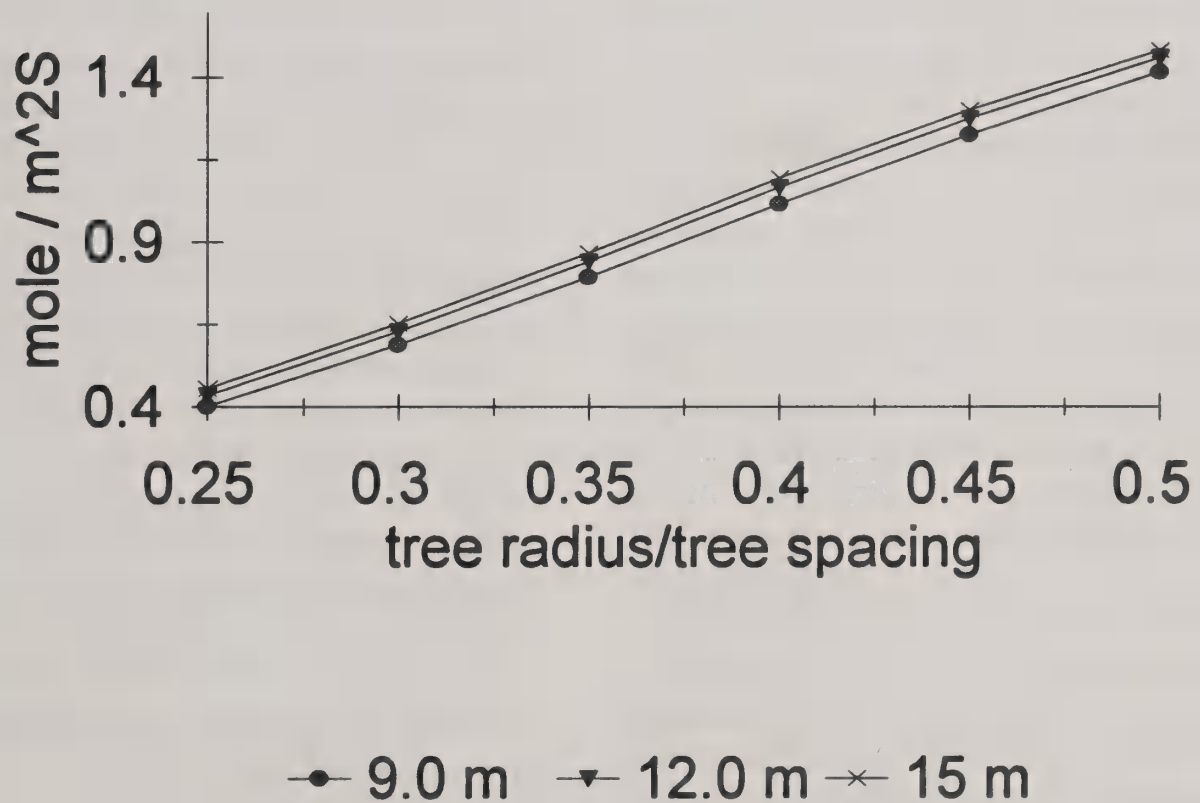
Figure 2. Light Interception per Crown Area

Figure 3. Light Interception per Ground Area

LEAF AREA-LEAF MASS RELATIONSHIP IN PECAN TREES

Jose Ernesto Frias-Ramirez[1] and Tim L. Jones[2]

Additional index words. Specific leaf area, leaf area index, foliage density, gap fraction

ABSTRACT

An experiment was carried out during the fall 1996 and 1997 to estimate leaf area, leaf mass and specific leaf area (SLA) of pecan trees. A pecan tree was cut down, harvesting its leaves, fruit and wood by quadrants in both years. Measurements of foliage density were made with the Plant Canopy Analyzer LAI-2000, LI-COR Inc. before cutting down the trees. One hundred leaves were sampled per quadrant from the first 0.6-1.0 m from the tip of branches. Another one hundred leaves were sampled from the rest of the branch's length for each quadrant, to get a total sample of eight hundred leaves per tree per year. The remaining leaves were harvested, dried and weighed to provide the leaf mass per quadrant and leaf mass for the whole tree. Leaf area and dry weight were determined at the laboratory by direct measurements of each sampled leaf per quadrant and tree. The leaf area of forty compound leaves was measured using a Delta T leaf area meter. The leaflets and the petioles of ten of the forty leaves were dissected and their area was measured by using two LI-COR leaf planimeters model LI-3000. A regression analysis was done to find leaf area-mass relationship at leaf, leaflet and branch scale.

SLA was calculated from direct measurements of leaf area and mass, as well as from non destructive measurements of leaf area made with the LAI-2000. Estimates of total leaf calculated from SLA and LAI-200 data were compared to the destructive leaf mass measurements per tree were obtained from the leaf area-mass relationships.

As expected, leaves were different in size and weight. Leaf area varied from 28.17 to 544.34 cm^2 in 1996, and from 18.52 to 324.85 cm^2, in 1997. The leaf mass had an average of 2.11 +/- 0.92 g in 1996 and 1.58 +/- 0.65 g in 1997. Leaf area and mass presented a good linear relationship. However, the slope of the line varied depending on the quadrants and leaf position. This may be the result of differences in leaf thickness caused by different light exposure. The average SLA measured directly was 92 cm^2/g for 1996 and 91 cm^2/g for 1997. The SLA estimated from light attenuation measurements (LAI-2000) was 107.27 cm^2/g for 1996, and 82.5 cm^2/g for 1997.

An equation to predict total leaf mass from indirect measurements of leaf area was obtained by averaging direct SLA estimates from the two years data:

$$T_{lm} = Tla \ / \ 9.1$$

Where: T_{lm} is total leaf mass in kilograms and Tla is the total leaf area in square meters.

The estimation error of leaf mass was 11% for 1996 and 1997. This represents a promising method to estimate the leaf mass of pecan trees

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from non destructive measurements of leaf area.

INTRODUCTION

Leaf area and leaf mass are closely related to light interception, photosynthesis, transpiration, growth rate and furthermore to yield (Ma, 1992). These parameters are important for forest and agricultural research as well for crop management practices .

Leaf area-mass relationships can be expressed by the Specific leaf area (SLA) (cm^2/g or m^2/Kg) which is the leaf area to leaf mass ratio (Reddy et al., 1989). SLA indicates leaf thickness. In addition, SLA has been related to leaf structure, growth and net photosynthesis (Barden, 1977). SLA also can be used in conjunction with leaf area to estimate leaf mass for nutrient balance calculations and growth estimates.

In most crops leaf area is defined by the leaf area index LAI. This term expresses the area of the aboveground plant components such as leaves, branches and fruit per unit area of ground in m^2/m^2 (Wells, 1990). Leaf area is usually determined directly for individual leaves using automatic leaf area meters, leaf area-leaf dimensions relations, or leaf area-weight ratios (Norman and Campbell, 1989). Although these methods require simple data, they are tedious and time consuming and involve destructive sampling. It can be practical for small crops but very hard to be used for fruit trees such as pecan.

An alternative way to measure the leaf area of a plant is the measurement of light attenuation by crops, known as a Gap Fraction Method. This method is based on the fraction of sky light attenuated by the canopy. (Wells, 1990; Wells and Norman, 1991).

Leaf mass is usually determined by simple weighting of foliage samples. However, when total mass of tree foliage is wanted, destructive sampling and weighing is impractical and prohibitive. An alternative way to define the foliage mass of trees is needed such as combining nondestructive leaf area measurements with SLA estimates.

Although several studies relating indirect and direct measurement of leaf area have been done in different crops, there is a lack of information for pecans. There is also a lack of data on SLA and the use of SLA to estimate total leaf mass from leaf area in pecan trees.

OBJECTIVES:

The objectives of this study were: to determine the SLA from destructive sampling and direct measurements of leaf area and mass in pecan trees. Determine the variability of SLA at leaflet, leaf and branch scale. Determine if leaf area measured by light interception produces SLA estimates comparable to direct measurements. Determine total leaf mass of pecan trees from leaf area measurements.

MATERIALS AND METHODS

Experiments were conducted in commercial pecan orchards during 1996 and 1997 to estimate the leaf area, leaf mass and specific leaf area. The first experiment was conducted in Berino, NM during October 1996. A 28-year-old Barton pecan tree growing on a Rincon rootstock and planted 30 by 45 feet apart from other trees was cut down and totally harvested. The second experiment was performed at San Miguel, NM cutting down and harvesting a 35-year-old Ideal variety pecan tree planted 30 by 30 feet apart. Harvesting, in both years, occurred when foliage, branches and fruit of pecan trees were at the final stage of growth.

The trees were divided in four quadrants. Each

quadrant consisted of a ninety-degree section facing north, east, south and west. Before cutting down the trees, measurements of width and height by quadrants were done to obtain the profile of the trees. The central point for the profile was the center of the trunk at the soil surface.

Foliage density (leaf area, m²/ volume of tree, m³) measurements were also made by quadrants using a Plant Canopy Analyzer LAI-2000, LI-COR Inc. To perform the readings a ninety-degree view cap was put on the light sensor of the Plant Canopy Analyzer to limit the view of the instrument to a quadrant of the tree. The foliage density measurements with the LAI-2000 were performed using the reading procedure for isolated trees with asymmetric canopy (Li-COR, 1992). This consists of taking two readings, one above the canopy reading "A," and one below the crown and close to the trunk of an individual tree canopy, reading "B." In 1996, the above canopy readings were taken outside of the orchard where a canopy did not block the light to the plant canopy analyzer. During 1997, above readings were done on top of the canopy by using a cherry picker machine.

The cutting, sampling and harvesting of trees, as well as the area and mass determinations for both 1996 and 1997, were performed using the same methodology. Before cutting the tree, leaves, nuts and husks were collected from the ground. The cutting process was done by sawing each branch one at the time, by quadrant. The branches were cut down and their length and diameter were measured. A sample of two hundred leaves was taken randomly from each quadrant in two positions. One hundred distal leaves were collected from the first 0.60-1.0 m of each branch (outer quadrants: Qout), and one hundred leaves were harvested from the rest of the branch's length (inner quadrants: Qin). The

remaining leaves in the quadrant, along with the nuts and husks were separated, saved in sacks, oven dried, and weighed. The main branch was also chopped down saving all the wood to get the total dry mass of wood per quadrant and per tree.

The 200 sampled leaves per quadrant (Qin and Qout) were taken to the laboratory to measure leaf area and dry mass. The leaf area was measured as follows: The area of forty compound leaves was measured using a Delta T leaf area meter. Ten of these forty leaves were used to determine the leaf area of individual leaflets and petioles using two leaf area planimeters model LI-3000, LI-COR, Inc. The leaflets and petiole were dissected from the leaves and run through the leaf area meters. The leaf area of remaining leaves (bulk and leftovers) was obtained from cumulative leaf area measurements with the Delta T area meter. All leaf area meters used to measure the leaf area, were calibrated to correct the leaf area of each sample. All leaves were oven dried at 65 Celsius degrees for 72 hours to obtain the dry mass. A regression analysis was done to find out if there was a relationship between leaf area and leaf mass by quadrant, leaf position and for the whole canopy of the pecan tree for each year's data.

The foliage density and canopy volume per quadrant were calculated from the field measurements by using the software support for the plant canopy analyzer C-2000-90 Version 2.14 (LI-COR, 1992). Foliage density and canopy volume were used to make an indirect estimate of mean leaf area per quadrant, and for the whole tree. Then measured leaf mass and indirect leaf area were used to calculate field estimates (indirect) of SLA. Direct SLA, was obtained for each sampled compound leaf and selected leaflets for all sampling positions by

dividing the measured leaf area by the measured leaf mass.

Average SLA was obtained from direct measurements of leaf area and leaf mass made in 1996 and 1997. This average was used to estimate the total leaf mass of a pecan tree. The predicted leaf mass was compared with the whole tree's leaf mass measured in both years.

RESULTS AND DISCUSSION

Leaf area varied from 28.17 to 544.34 cm^2 in 1996, and from 18.52 to 324.85 cm^2, in 1997. The mass of compound leaves presented an average of 2.11 +/- 0.92 g in 1996, and 1.58 +/- 0.65 g in 1997. Direct measurements of leaflet area for 1996 and 1997 showed a range of 1.93 to 48.23 cm^2 with a mass range from 0.01 to 0.45 g.

A good linear relationship was found between the leaf mass and area for leaflets, compound leaves and petioles in 1996 and 1997. Figures 1 and 2, show examples of the area-mass relationships for leaves, leaflets and petioles measured in 1996. The slope of the lines in these graphs is the reciprocal of SLA. These figures show that in the same quadrants (i.e., QI) the SLA is the same for leaflet and leaves; however, the SLA of the leaflets might be different from leaves. The SLA from petioles is different from both leaves and leaflets.

Tables 1 and 2 show values of SLA measured directly in the laboratory during 1996 and 1997 respectively. The SLA estimated from direct measurements varied from 71 to 113 cm^2/g with an average of 92 cm^2/g in 1996 and varied from 72 to 108 cm^2/g with an average of 91 for 1997.

These data show no significant differences in SLA among years on leaf and leaflets. There

might be a slightly significant variation in SLA within positions. Observed SLA was always higher for the medial leaves. This is consistent with the distal leaves being thicker because of receiving more sunlight.

Tables 3 and 4, show mean SLA estimates calculated from the direct and nondestructive leaf area measurements. Average SLA estimated using field measured by field measurements of light attenuation varied from 33.5 to 157.1 cm^2/g with an average of 107.27 cm^2/g for 1996 and varied from 63.0 to 132.1 cm^2/g with an average of 82.5 for 1997. Preliminary statistical analysis indicate that these differences are not statistically significant.

Total leaf mass per tree was estimated for both years using indirect leaf area measurements (table 5). The equation used to predict total leaf mass from total leaf area is:

$$T_{lm} = Tla \ / 9.1$$

where:
T_{lm} : Total leaf mass (kg)
Tla: total leaf area (m^2)

This equation underestimated total leaf mass for both 1996 and 1997 with an estimation error of 11%. This represents a promising alternative to estimate the leaf mass of pecan trees by non destructive measurements of leaf area.

CONCLUSIONS

SLA appears to be the same at leaf and leaflet scale (still being analyzed). Direct SLA and field SLA were not significantly different for both 1996 and 1997. Outside leaves may show lower direct SLA than inside leaves for 1996 and 1997 (still being analyzed). An estimate of total leaf mass per tree for 1996 and 1997 was

obtained from average SLA and indirect leaf area
measurements with an estimation error of 11%.

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Table 1. Specific Leaf Area (cm²/g) by sampling position, measured directly in 1996.

Quadrant	in	out	mean
I	88	80	84
II	113	105	109
III	91	71	81
IV	108	75	92

Table 2 Specific Leaf Area (cm²/g) by sampling position, measured directly in 1997.

Quadrant	in	out	mean
I	103	73	88
II	94	72	83
III	120	88	104
IV	108	66	87

Table 3. Mean specific leaf area (cm²/g) by method for leaf area measurements for 1996.

Quadrant	Leaf mass (g)	Direct SLA (cm²/g)	Field SLA (cm²/g)
I	9461.2	84	157.1
II	10876.3	109	82.3
III	10865.7	81	156.2
IV	33096.8	92	33.5

Table 4. Mean specific leaf area (cm²/g) by method for leaf area measurements for 1997.

Quadrant	Leaf mass (g)	Direct SLA (cm²/g)	Field SLA (cm²/g)
I	14400	88	69.8
II	11500	83	65.5
III	13000	104	63.0
IV	11500	87	132.1

Table 5. Estimates of total leaf mass per tree by mass equation.

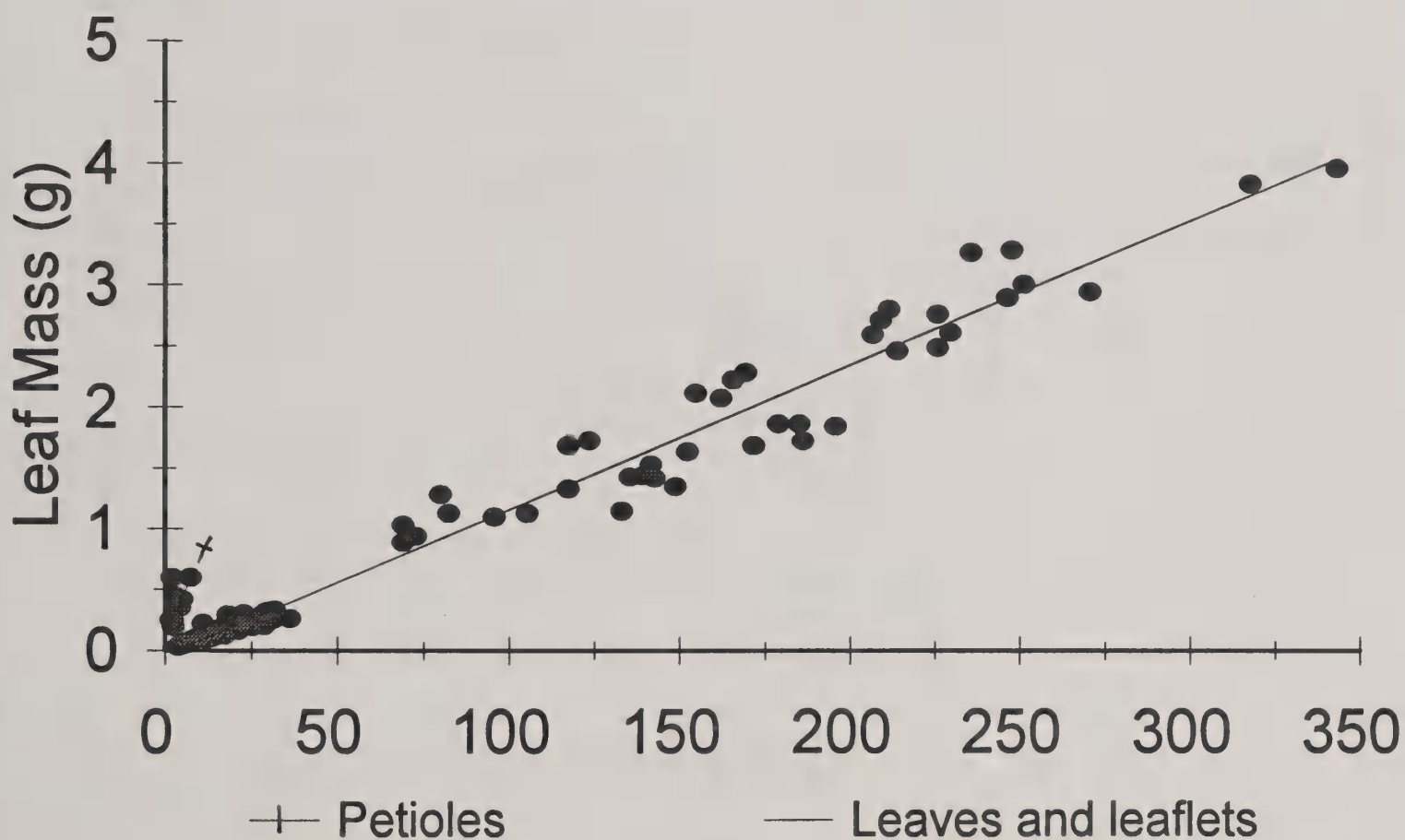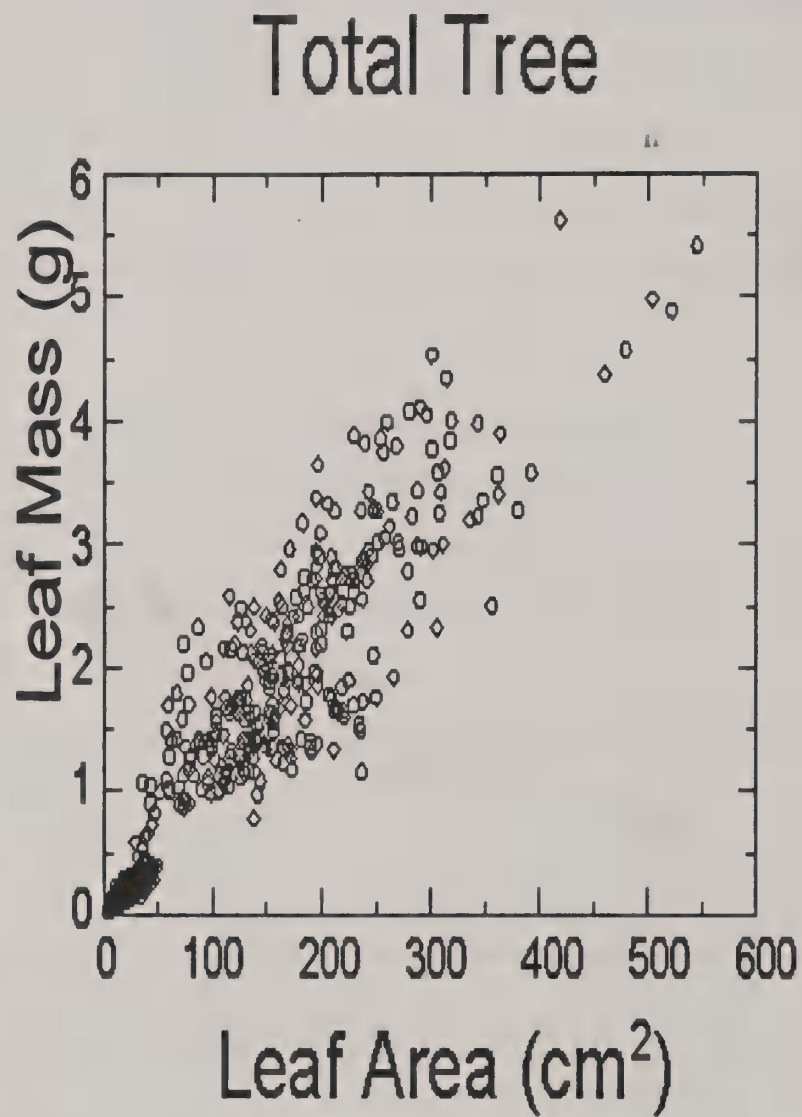|	1996		1997	
Mass Equation	Mass (kg)	Error %	Mass (kg)	Error %
Direct measurement	64.29		50.4	
$T_{lm} = T_{la} / 9.1$	57	- 11	45	- 11

Figure 1. Plot of leaf area -mass relationships , quadrant I (in) 1996

Figure 2. Plot of the area-mass relationship for leaflets and whole leaves for an entire tree sampled in 1996.

Green Lacewings As Predators of Pecan Aphids in Southern Arizona

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SUMMARY:

A census of the population dynamics of pecan aphids and their predators on 'Wichita' pecans was conducted at Farmers Investment Company's orchard in Southern Arizona in 1997 and the beginning of 1998. The census revealed that two aphids species, the black margined pecan aphid, *Monelliacaryella* Fitch, and the black pecan aphid, *Monelliopsis caryaefolia* Davis were the only aphid species present, and that green lacewings were the most abundant aphid predators.

Chrysoperla comanche Banks was the most dominant species, hatching from 30-65% of the compound leaves bearing lacewing eggs, and was present the entire growing season. *Chrysopa nigricornis* Burmeister was found on a lower percentages of the leaves (less than 17%). However, there were more *C. nigricornis* eggs present on each compound leaf (15-35) because this species lays large clutches of eggs in contrast to *C. comanche*, which deposit eggs singly. Eggs of other lacewing species were found in a lower number.

An analysis of the relationship between the aphid density on compound leaves with and without green lacewing eggs present suggest that the female lacewings prefer to oviposit on leaves with higher aphid densities.

The field data presented suggests that species of green lacewings make an important contribution to the natural control of pecan aphids in Southern Arizona.

Interactions Between Pecan Aphids, Ants and Lady Beetles in the Pecan Orchard

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ABSTRACT

Lady beetles are important predators of aphids on pecan trees. The lady beetles are deterred by red imported fire ants. Ants were more destructive to convergent lady beetles than to Asian lady beetles. Defensive behaviors of Asian lady beetles against attack by red imported fire ant include reflex bleeding, cessation of walking, and biting the ants. Convergent lady beetles, on the other hand, would fly or walk off the plant following an encounter with red imported fire ant. Pecan aphid populations were reduced by removing ants from the pecan tree crown with an application of chlorpyrifos in a band around the tree trunk.